



SPECIAL ISSUE: PREDATION

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Feral Swine Impacts on Agriculture and the Environment

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Introduction

More than 30 species of exotic free-ranging mammals have become established in the United States since European colonization (De Vos et al., 1956; McKnight, 1964; Roots, 1976). These species often become serious economic pests and can have grave consequences on their host environments (Cottam, 1956; De Vos et al., 1956; Mayer and Brisbin, 1991). True wild pigs (*Suidae*) are not native to the United States. Only the collared peccary (*Tayassu tajacu*; Tayassuidae) that inhabits the southwestern and south-central parts of the United States is native (Mayer and Brandt, 1982; Mayer and Wetzel, 1986). Feral swine (*Sus scrofa*) in the United States have originated from varieties of domestic swine, Eurasian wild boar, and their hybrids (Jones, 1959; Wood and Lynn, 1977; Rary et al., 1968; Mayer and Brisbin, 1991). Domestic swine were introduced to the United States as early as 750-1000 A.D. during the settlement of the Hawaiian Islands (Towne and Wentworth, 1950; Joesting, 1972; Smith and Diong, 1977). Christopher Columbus introduced domestic swine to the West Indies during the 1400s, where they proliferated and became pests. In the 1500s, Spanish explorers, such as DeSoto and Cortez, were the first to bring domestic swine to the United States mainland (Towne and Wentworth, 1950; Beldon and Frankenberger, 1977). By the 1960s, domestic swine and Eurasian wild boar were established in >20 states (McKnight, 1964). Swine introductions have intentionally or accidentally occurred by a variety of means,

including: 1) translocation to establish populations for hunting, 2) escapees from shooting preserves or confinement operations, 3) avoidance of capture by domestic pigs in free-ranging livestock operations, 4) abandonment by their owners, and 5) dispersal from established feral populations (Gipson et al., 1997; Witmer et al., 2004).

Feral swine are the most abundant free-ranging, exotic ungulate in the United States (McKnight, 1964; Decker, 1978) and have become widespread because of their reproductive potential and adaptability to a wide range of habitats. Like domestic swine, litter size depends on the sow's age, nutrition, and time of year. Feral swine are capable of producing two litters per year with average litter size varying from 4.2 to 7.5 piglets (Taylor et al., 1998), but up to 10 piglets can be born during ideal conditions (Conquenot et al., 1996). Mayer and Brisbin (1991) and Mackey (1992) report feral swine populations in 23 states. A Southeastern Cooperative Disease Study (1994) and Nettles (1997) point out an additional 16 states with feral swine populations. An estimated population of 4 million feral swine currently occur in the United States (Pimentel et al., 2000) with the largest populations inhabiting Texas (1 to 1.5 million; Pimentel et al., 2000), Florida (>500,000; Layne, 1997), Hawaii (80,000; Mayer and Brisbin, 1991), and California (70,000; Barrett, 1993). Since 1965, feral swine have expanded their range from 15 (26%) to 45 (78%) of the 58 California counties (Frederick, 1998). Feral swine populations continue to increase (Gipson et al., 1997) because they possess the greatest reproductive potential of all free-ranging, large mammals in the United States (Wood and Barrett, 1979; Hellgren, 1999) and

because of the absence of large native predators (e.g., mountain lion (*Felis concolor*) and wolves (*Canis lupus*) over much of the area occupied by feral swine. In southwest Florida where feral swine and a large predator coexist, feral swine is the most common food item (42%) in Florida panther (*F. c. coryi*) scats (Maehr et al., 1990), which may suggest that the presence of a large predator helps regulate feral swine density and associated damage.

Environmental Damage and Wildlife Depredation

Environmental Damage

Feral swine are generalists. Their omnivorous diet allows them to utilize a variety of food sources and to thrive in a wide range of environments. The majority of their diet consists of grasses, forbs, and soft and hard mast such as shoots, roots, tubers, fruit, and seeds. Acorn (*Quercus* spp.) and hickory (*Carya* spp.) nuts are two important food items that feral swine use seasonally (Mungall 2001) and may lead to competition with other wildlife (Yarrow and Kroll, 1989). Feral swine also eat a variety of invertebrates including earthworms, leeches, grasshoppers, centipedes, beetles, and other arthropods. As a predator, feral swine eat salamanders, frogs, fish, crabs, snakes, turtles, rodents, muskrats (*Ondatra zibethicus*), eggs and chicks of ground-nesting birds, white-tailed deer fawns (*Odocoileus virginianus*) (Hellgren, 1993), and livestock. Feral swine must forage almost continuously because their simple stomach is not as efficient as a ruminant's multi-chambered digestive system — hence the expressions “as greedy as a pig” and “eats like a pig.”

Feral swine negatively impact natu-

ral plant communities (Bratton, 1975; Wood and Barrett, 1979; Stone and Keith, 1987) and may seriously impact agricultural ecosystems (Singer et al., 1982). Feral swine rooting activity, digging for food with their snout, loosens the soil and accelerates erosion, sets back plant succession, reduces earthworm activity, and exacerbates exotic plant invasion (Mungall, 2001). Damage from rooting, trampling, and compaction directly and indirectly impacts plant regeneration, plant community structure (Bratton, 1975), soil properties (Lacki and Lancia, 1983), nutrient cycling (Tate, 1984), and water infiltration (Mungall, 2001). Rooting and incidental damage may give exotic plants an ecological advantage over native plants (Howe and Bratton, 1976) because exotic plants are typically better adapted at colonizing disturbed areas. Additionally, feral swine may help spread root-rot fungus (*Phytophthora cinnamomi*), which causes disease in native vegetation (Kliejunas and Ko, 1976).

Habitat damage by feral swine is most pronounced in wet environments (e.g., Choquenot et al., 1996; Engeman et al., 2004). Exposed marsh shoreline is particularly susceptible to damage because the shoreline and shallower water is typically dominated by shrubs and herbs, which are attractive forage (Engeman et al., 2003). Feral swine also use upland habitats and have been documented impacting longleaf pine (*Pinus palustris*) regeneration (Lipscomb, 1989) and southern hardwood forest composition (Wood and Lynn, 1977; Lacki and Lancia, 1986).

Wildlife Depredation

Feral swine impact native wildlife in a variety of ways, depending upon the habitat, density of feral swine, and other extraneous factors. About 400 of the 958 wildlife species listed as threatened or endangered under the Endangered Species Act are considered to be at risk primarily because of competition or predation by non-indigenous species (Nature Conservancy, 1996; Wilcove et al., 1998; Pimentel et al., 2002). In Florida, feral swine have contributed to the decline of at least 22 plant species and 4 species of amphibians listed as rare, threatened, endangered, or of special concern (USDA, 2002). In the southern United States, feral swine pre-

dition may negatively affect bobwhite quail (*Colinus virginianus*) and wild turkey (*Meleagris gallopavo*) nest success (Synatzske, 1979). Tolleson et al. (1993) constructed 192 simulated quail nests in Texas and reported that feral swine was the most common predator (28%) of simulated nests. They concluded feral swine could have detrimental effects on bobwhite quail populations depending upon the density of quail and feral swine, quail nesting cover, and quantity and diversity of other swine food sources.

On some southeastern U.S. beaches, feral swine have become significant predators of marine turtle nests by excavating and feeding on the eggs (Stancyk, 1982; Lewis et al., 1996). Feral swine seriously threaten the nesting success of several threatened and endangered marine turtles including: the loggerhead (*Caretta caretta*) (federal; threatened); green (*Chelonia mydas*) (federal; endangered); leatherback (*Dermochelys coriacea*) (federal; endangered); hawksbill (*Eretmochelys imbricata*) (federal; endangered); and the Kemp's ridley (*Lepidochelys kempii*) (federal; endangered), destroying up to 80% of nests in some regions of Florida (USDA, 2002). It has become critical to monitor and manage nest predation to ensure the existence of these threatened and endangered turtles. USDA/Wildlife Services (WS) is working with various state and federal agencies to reduce turtle nest predation by protecting nests with portable fences and reducing feral swine densities through cage trapping and culling.

Livestock Depredation and Agricultural Crop Damage

Shortly after Christopher Columbus introduced swine to the West Indies, feral swine depredated cattle (Ensminger, 1961) and consumed agricultural crops such as maize and sugar cane (Donkin, 1985). Frederick (1998) surveyed all 58 county agricultural commissioners in California and reported \$1,731,920 in feral swine damage. This figure is likely underestimated because only 69% of county agricultural commissioners responded, and the exact number and monetary value of damaged resources was conservatively estimated (Frederick, 1998). Livestock and wildlife depredation and agricultural and environmental damage will likely continue

to increase as feral swine flourish and humans encroach wildlife habitat.

Livestock Depredation

Feral swine are well documented as significant predators of lambs (*Ovis aries*) in Australia (Moule, 1954; Rowley, 1970, Pavlov et al., 1981, Choquenot et al., 1997) where 4 to 20 million feral swine exist (Emmerson and McCulloch, 1994; Pimentel et al., 2000). Feral swine prey on a variety of other livestock including goats (*Capra hircus*), newborn cattle (*Bos taurus*), and exotic game. Animal matter typically makes up only a small percentage of their diet, but considerable economic loss can occur from livestock depredation. In Australia, the greatest losses occur in sheep (wool and meat loss) and cattle production (Tisdell, 1991). In the semi-arid rangelands of Australia, losses of newborn lambs from feral swine predation have been as high as 32% (Plant et al., 1978), with a multiple-year average loss of 19% (Pavlov et al., 1981). Choquenot et al. (1997) found that the rate of lamb predation increased with feral swine density, until reaching a maximum of 29% at a density of 4 to 8 pigs/km². Predation typically occurs on lambing or calving grounds, possibly because of the attraction of afterbirth and fetal tissue (Wade and Bowns 1985; Beach, 1993). Occasionally, livestock giving birth are killed and fed upon (Wade and Bowns, 1985). Predation occurs throughout the age classes for sheep and goats, but newborn or immature animals are usually targeted (Beach, 1993). In fact, feral swine preyed upon twin lambs on average 5 to 6 times more than single lambs (Choquenot et al., 1997). This is likely attributed to twin lambs being smaller and weaker than their single counterparts (Alexander, 1984) and the divided vigilance of their mother. Feral swine have been observed to disrupt flocks 78% of the occasions when within 100 m and caught lambs during 24% of chases (Pavlov and Hone, 1982). Feral swine predation may be difficult to document because the entire carcass is typically consumed, leaving little evidence. Additionally, feral swine will scavenge dead animals including other swine carcasses (Hanson and Karstad, 1959; Nichols, 1962). Therefore, predation may be mistaken as low productivity in

the herd, or vice-versa, when scavenged stillborns and aborted fetuses are mistaken as cases of depredation.

Feral swine usually follow a characteristic feeding pattern that makes identification of depredation possible if the entire carcass is not consumed (Pavlov and Hone, 1982). Death typically occurs by biting and crushing the skull or neck (Frederick, 1998). A good indicator of feral swine predation is that the prey's carcass will be skinned out with the rumen or stomach contents consumed (Wade and Bowns, 1985). Feral swine tracks are distinct and may help decipher cause of mortality when the soil and nearby vegetation have been disturbed.

Feral swine cause serious economic loss to the livestock industry, although exact numbers and values are largely unknown. This may be caused by misidentification of the cause of predation. For example, signs of coyote (*Canis latrans*) and feral swine predation appear very similar; therefore cases reported as coyote predation may actually be feral swine. This is especially plausible in Texas, where high densities of coyotes and feral swine exist and target newborn animals. Coyotes typically attack sheep and goats with a bite to the throat, causing death from suffocation and shock, then feed on their prey (Wade and Bowns, 1985) starting at the flank or just behind the ribcage. Coyotes typically leave splintered bones, chewed ribs, and scattered pieces of skin, fur, tendons, and bones (Wade and Bowns, 1985). Conversely, black bear (*Ursus americanus*) normally do not consume the rumen and its contents, but the carcass will appear skinned out (Wade and Bowns, 1985). Black bears usually do not scatter their prey, and the hide and skeleton will be mostly intact. Large claw marks across the shoulders and back may provide additional clues.

The annual economic loss from feral swine predation in the United States is unknown; however feral swine predation on livestock in the United States does not appear to be as prevalent as in Australia, where >\$80 million is lost annually (Emmerson and McCulloch, 1994). In Texas, Rollins (1993) reported that 33% of county agricultural agents listed livestock depredation by feral swine as a problem with losses directed towards sheep and goats. In 1990, 1,243 sheep and goats were documented as being lost

to feral swine in Texas, with an estimated value of \$63,000 (Rollins, 1993). Barrett and Birmingham (1994) reported 1,473 sheep, goats, and exotic game animals were killed by feral swine in Texas and California in 1991. In a more recent survey, 23% of county agricultural commissioners in California reported livestock depredation by feral swine (Frederick, 1998); total economic loss was not estimated. Texas produces 1.1 million goats annually, about 90% of the goats raised in the United States (Scrivner et al., 1985), and Pearson (1986) reported that predators killed 18% of adults and 34% of kids. The number of goats lost to feral swine predation is unknown, but is likely substantial (>\$1 million) considering \$5.7 million was lost to coyotes in the United States in 1990 (NASS 1991). Additionally in 1990, combined sheep and lamb losses from coyotes were valued at \$18.3 million in the United States (NASS, 1991). Where practical, ranchers should closely monitor livestock and confine pregnant animals to protected areas during calving and lambing seasons to reduce susceptibility to predation. An understanding of field sign and different behavioral cues can help determine cause of mortality and the impact of feral swine predation.

Feral Swine and Disease

Annual pork sales in the United States exceed \$11 billion with retail sales exceeding \$34 billion (Witmer et al., 2004). Therefore, there is concern relative to the role feral swine could pose to the pork industry as a reservoir for disease. However, only 26% of Texas agricultural extension agents were concerned about disease transmission to livestock (Rollins, 1993). Feral swine can harbor at least 30 significant viral and bacteriological diseases (Williams and Barker, 2001) and feral swine in Florida have been documented to have as many as 45 different parasites and infectious diseases (Forrester, 1991). These include 37 parasites (12 protozoans, 17 nematodes, 1 acanthocephalan, 1 sucking louse, 4 ticks, and 2 mites), 7 bacteria, and 1 virus. Eight of these parasitic and infectious diseases can infect humans (brucellosis, leptospirosis, salmonellosis, toxoplasmosis, balantidiasis, trichinosis, trichostrongylosis, and sarcoptic mange). All four

species of ticks opportunistically infect and feed on humans. The diseases of most concern to the livestock industry include pseudorabies, swine brucellosis, bovine tuberculosis, leptospirosis, and vesicular stomatitis (Becker et al., 1978; Williams and Barker, 2001). These and the possibility of an exotic disease outbreak, such as foot-and-mouth disease, a contagious viral disease of ungulates (e.g., pigs, sheep, cattle, goats, and deer) (Pech and McIlroy, 1990), or classic swine fever (a contagious viral disease of wild and domestic swine), could have serious repercussions for livestock industries (Hone et al., 1992). On the other hand, feral swine may serve as a surveillance tool for the early detection of exotic diseases (Mason and Fleming, 1999; Witmer et al., 2004). These potential health aspects should be kept in mind when considering feral swine range expansion, translocation (Forrester, 1991), and tolerance around livestock operations.

Crop Damage

Feral swine damage pasture and agricultural crops by consumption, rooting, digging, and trampling. In Australia, feral swine cause considerable agricultural crop damage with >\$100 million lost annually (Choquenot et al., 1996). The greatest losses occurred in wheat, sorghum, barley, oilseeds, sugar cane, oats, and maize, in that order (Tisdell, 1991). In the United States, feral swine damage \$800 million in agricultural crops each year, assuming that 4 million feral swine inhabit the United States and cause \$200 worth of damage per pig (Pimentel et al., 2002). This estimate is likely very conservative because it does not consider livestock predation, disease transmission, or environmental degradation.

In Texas, the most common complaint or concern (75%) in a survey conducted by Rollins (1993) was damage to agricultural crops including hay, small grains (milo, rice, and wheat), corn, and peanuts. Other crops affected were vegetables, watermelons, soybeans, cotton, orchards, horticultural crops, and conifer seedlings. Seventy-two percent of surveyed extension agents reported additional damage to ranch facilities (e.g., fences, water supply, irrigation ditches, and guzzlers).

Population Control and Management

No panacea for feral swine control, management, or eradication currently exists (Choquenot et al., 1996). In most states feral swine are unprotected or classified as an agricultural pest, therefore hunting methods are liberal and swine can be harvested throughout the year. States where feral swine are classified as game animals rely on hunter harvest to control or regulate swine populations; however, sport hunting has had negligible effects on swine population management (Barrett and Stone, 1993). Feral swine can be controlled by several techniques including shooting, trapping, and, in overseas locations, with toxicant baiting (Tisdell, 1982). In Australia, toxicant baiting [e.g., sodium monofluoroacetate (Compound 1080), warfarin] has been used to reduce feral swine populations in some areas by 58 to 73% depending upon the length of the poisoning campaign (Hone and Pederson, 1980; Hone, 1983; Pech and Hone, 1988). Careful consideration and monitoring must be applied when using toxicants because other non-target species may be harmed (Stone et al., 1988). Frightening devices are ineffective and no repellents or toxicants are registered for feral swine use in the United States (Barrett and Birmingham, 1994). Other lethal means for eradication include aerial hunting with helicopters, hunting with dogs, or shooting at night over bait. Saunders and Bryant (1987) used aerial shooting over five days to reduce a population by 80%. Hunting with dogs can also be effective at reducing feral swine populations in local areas (Barrett and Birmingham, 1994). Trapping and snaring followed by euthanasia can also help reduce swine density and nuisance animals. Trapping with corral traps and portable drop-gate traps can be effective, but efficacy varies seasonally with production of natural food sources (e.g., acorns) (Barrett and Birmingham, 1994). Leg snares can be effective, but should be implemented with caution in areas where livestock, deer, or other non-target animals may be present. Access points such as fence under-passes or pen entrances not used by non-target animals are ideal. Other control measures to alleviate damage include excluding feral swine with wire mesh fencing or electric fence. No fence design is completely pig-

proof, but they can significantly reduce feral swine movement into protected areas. Wire mesh fencing or adding an electrified wire to an established fence 15 to 20 cm off the ground appear to be the most effective means of excluding feral swine (Hone and Atkinson, 1983). However, due to the associated cost of these control measures, agricultural producers must weigh the cost of taking precaution to their expected loss to determine if action is cost-effective. An integrated approach may be more feasible and may help alleviate feral swine recognition and avoidance of specific control practices (Choquenot et al., 1996).

One of the greatest needs for feral swine management is a practical means for indexing populations (Choquenot et al., 1996). Knowledge of relative swine population abundance and spatial distribution is valuable for timing control programs, optimally locating control sites, and evaluating control efficacy. A variety of methods have been applied to estimate absolute abundance of feral swine, though they often require many resources and produce mixed results (Choquenot et al., 1996). Assessments of populations can be done by directly estimating population density through line-transect (e.g., Burnham et al., 1980) or mark-recapture estimation (e.g., Otis et al., 1978). An alternative is to calculate an index reflective of population abundance (e.g., Caughley, 1977). Engeman et al. (2001) recently evaluated a passive-tracking method in Florida to index the relative abundance and distribution of feral swine in an area and to evaluate the impact of control programs. The technique is easy to use and allows managers to index feral swine density around agricultural operations. Knowledge of feral swine density will aid in making decisions about whether control measures are warranted. If density is low, then the associated risk of depredation may be acceptable and no control measures may be necessary. However, if feral swine density is high, then it may be beneficial to take precaution and reduce the threat of damage.

Discussion

Despite the negative impacts feral swine have on agriculture and the environment, humans continue to introduce feral swine to new areas (Howells and

Edwards-Jones, 1997; Leaper et al., 1999) and allow range expansion. Some individuals, mostly feral swine hunters and landowners that generate revenue from hunting leases, encourage feral swine and consider them a desirable big game species. In most states with large populations (e.g., Texas, Florida, California, and Hawaii), feral swine are considered a big game species and year-long hunting seasons have been established to "control" numbers. In Texas, Rollins (1993) regarded feral swine hunting as a sport for locals more so than nonresidents with an average cost of \$169 per hunter. However, this may be changing; in 1998 the Texas Parks and Wildlife Department generated over \$1 million from the sale of 30,512 hog permits to nonresidents (Chambers, 1999). Hunting may serve to alleviate disease transmission and predation by reducing the number of feral swine at the livestock interface. Ranchers and farmers should be encouraged to hunt feral swine, grant hunting permission, and participate in state hunter access programs.

Although feral swine hunting generates income for some, the damage to private and public property and natural resources is hardly justifiable. Ranchers and farmers should understand the potential risks and have cost-effective means available to them for feral swine control. In areas where feral swine pose a threat to natural resources, most conservation organizations promote the eradication or reduction of feral swine populations. Until a paradigm shift occurs and society understands that the negative impacts feral swine cause outweigh any immediate or potential benefits, some current conservation strategies for native wildlife and maintenance of disease-free, domestic-swine populations will be at risk.

In the United States, ranchers and farmers operating in feral swine-occupied areas need more information regarding feral swine damage and means to alleviate potential losses. Research is needed to determine the rate of predation relative to feral swine density, assess the economic loss caused by feral swine predation, quantify the rate of disease transmission to domesticated livestock, and to develop economical means to alleviate feral swine damage. Current damage management techniques in the United States include fencing, snares,

cage traps, and various methods of hunting. In Australia, the use of aerially delivered toxic bait is legal, and it is the most efficient means of quickly reducing feral swine numbers. Resource management agencies in the United States should consider following Australia's lead and manifesting a management plan for the eradication of feral swine in areas that have the potential to be exposed to exotic livestock diseases. This would likely require the registration and approval of a toxicant and bait delivery system that targets feral swine with minimal impact on non-target species and the environment. As Tisdell (1991:168) stated, "the question has been raised whether feral swine should be managed on a sustainable yield basis, with an eradication strategy pursued only if an exotic livestock disease, such as foot-and-mouth, be accidentally introduced." This statement is very reactionary; we must remember that feral swine are an exotic species and pose a significant threat to agriculture and the environment. Strict control of feral swine populations is responsible management. Until state agencies address feral swine populations and their expansion, the damage they cause will likely continue to increase.

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