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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.

Literature Cited

- Alexander, G. 1984. Constraints to lamb survival. Reproduction in sheep. Pages 199-209 in D. R. Lindsay, and D. T. Pearce, editors. Australian Wool Corporation Technical Publication, Australian Academy of Science, Canberra.
- Barrett, R. H. 1993. Feral swine: The California experience. Pages 107-116 in C. W. Hanselka and J. F. Cadenhead, editors. Feral swine: A compendium for resource managers. Texas Agricultural Extension Service, Kerrville, TX, USA.
- Barrett, R. H., and C. P. Stone. 1993. Hunting as a control method for wild pigs in Hawaii Volcanoes National Park: A report for resource management. Research Division, Hawaii Volcanoes National Park Service, U.S. Department of the Interior, Hawaii National Park, HI, USA.
- Barrett, R. H., and G. H. Birmingham. 1994. Wild pigs. Pages D65-D70 in S. Hygnstrom, R. Timm, and G. Larsen, editors. Prevention and Control of Wildlife Damage. Cooperative Extension Service, University of Nebraska, Lincoln, NE, USA.
- Beach, R. 1993. Depredation problems involving feral hogs. Pages 67-75 in C. W. Hanselka and J. F. Cadenhead, editors. Feral swine: A compendium for resource managers. Texas Agricultural Extension Service, Kerrville, TX, USA.
- Becker, H. N., R. C. Belden, T. Brevault, M. J. Burrige, W. B. Frankenberger, and P. Nicoletti. 1978. Brucellosis in feral swine in Florida. *Journal of the American Veterinary Medical Association* 173: 1181-1182.
- Beldon, R. C. and W. G. Frankenberger. 1977. Management of feral hogs in Florida — past, present, and future. Pages 5-10 in G. W. Wood, editor. Research and management of wild hog populations. Clemson University, Georgetown, SC, USA.
- Bratton, S. P. 1975. The effects of the European wild boar, *Sus scrofa*, on gray beech forest in the Great Smoky Mountains. *Ecology* 56(6): 1356-1366.
- Burnham, K. P., D. R. Anderson, J. L. Laake, 1980. Estimation of density from line transect sampling of biological populations. *Wildlife Monographs* 72.
- Caughley, G. 1977. Analysis of vertebrate populations. Wiley and Sons, New York, NY, USA.
- Chambers, M. 1999. Conserving a resource. Pages 115-116 in Proceedings of the feral swine symposium. Texas Animal Health Commission. Austin, TX, USA.
- Choquenot, D., J. McIlroy, and T. Korn. 1996. Managing vertebrate pests: Feral pigs. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.
- Choquenot, D., B. Lukins, and G. Curran. 1997. Assessing lamb predation by feral pigs in Australia's semi-arid rangelands. *Journal of Applied Ecology* 34: 1445-1454.
- Cottam, C. 1956. The problem of wildlife introductions - its successes and failures. Proceedings of the 46th Convention of International Association of Game, Fish, and Conservation Committee, 94-111.
- De Vos, A., R. H. Manville, and R. G. Van Gider. 1956. Introduced mammals and their influence on native biota. *Zoologica* 41: 163-194.
- Decker, E. 1978. Exotics. Pages 249-256 in J. L. Schmidt and D. L. Gilbert, editors. Big game of North America: Ecology and management. Stackpole Books, Harrisburg, PA, USA.
- Donkin, R. A. 1985. The peccary - with observations on the introduction of pigs to the New World. *Transactions of the American Philosophical Society* 75(5): 1-152.
- Engeman, R. M., B. Constantin, M. Nelson, J. Woolard, and J. Bourassa. 2001. Monitoring changes in feral swine population and spatial distribution of activity. *Environmental Conservation* 28: 235-240.
- Engeman, R. M., H. T. Smith, R. G. Severson, M. M. Severson, S. A. Shwiff, B. Constantin, and D. Griffin. 2003. Amount and economic valuation of feral hog damage to a unique basin marsh wetland in Florida. Florida Park Service, 2003 "Partnership" Technical Report. Tallahassee, FL. 5p.
- Engeman, R. M., H. T. Smith, S. A. Shwiff, B. Constantin, M. Nelson, D. Griffin, and J. Woolard. 2004. Estimating the prevalence and economic value of feral swine damage to native habitats in three Florida state parks. *Environmental Conservation*. 30: In press.
- Emmerson, G., and J. McCulloch. 1994. Feral peril: Queensland's introduced plants and animals. Queensland Parliamentary Library, Brisbane, Australia.
- Ensminger, M. E. 1961. Swine science. The Interstate Printers and Publishers, Danville, IL, USA.
- Forrester, D. J. 1991. Parasites and diseases of wild mammals in Florida. University of Florida Press, Gainesville, FL, USA.
- Frederick, J. M. 1998. Overview of wild pig damage in California. Proceedings of the Vertebrate Pest Conference 18: 82-86.
- Gipson, P. S., B. Hlavachick, T. Berger, and C. D. Lee 1997. Explanations for recent range expansions by wild hogs into midwestern states. Great Plains Wildlife Damage Control Workshop 13: 148-150.
- Hanson, R. P., and L. Karstad. 1959. Feral swine in the southeastern United States. *Journal of Wildlife Management* 23: 64-75.
- Hellgren, E. C. 1993. Biology of feral hogs (*Sus scrofa*) in Texas. Pages 50-58 in C. W. Hanselka and J. F. Cadenhead, editors. Feral swine: A

- compendium for resource managers. Texas Agricultural Extension Service, Kerrville, TX, USA.
- Hellgren, E. C. 1999. Reproduction in feral swine. Pages 67-68 in Proceedings of the feral swine symposium. June 2-3. Texas Animal Health Commission, Fort Worth, TX, USA.
- Hone, J. 1983. A short-term evaluation of feral pig eradication at Willandra in western New South Wales. *Australian Wildlife Research* 10: 269-275.
- Hone, J., and H. Pederson. 1980. Changes in a feral pig population after poisoning. *Proceedings of the Vertebrate Pest Control Conference* 9: 176-182.
- Hone, J., and B. Atkinson. 1983. Evaluation of fencing to control feral pig movement. *Australian Wildlife Research* 10: 499-505.
- Hone, J., R. Pech, and P. Yip. 1992. Estimation of the dynamics and rate of transmission of classical swine fever (hog cholera) in wild pigs. *Epidemiology and Infection* 108: 377-386.
- Howe, T. D., and S. P. Bratton. 1976. Winter rooting activity of the European wild boar in Great Smokey Mountains National Park. *Castanea* 41: 256-264.
- Howells O., and G. Edwards-Jones. 1997. A feasibility study of re-introducing wild boar (*Sus scrofa*) to Scotland: Are existing woodlands large enough to support a minimum viable population? *Biological Conservation* 81: 77-89.
- Joesting, E. 1972. Hawaii, an uncommon history. W.W. Norton and Company, New York, NY, USA.
- Jones, P. 1959. The European wild boar in North Carolina. North Carolina Wildlife Resources Commission, Division of Game, Raleigh, NC, USA.
- Kliejunas, J. T., and W. H. Ko. 1976. Dispersal of *Phytophthora cinnamomi* on the island of Hawaii. *Phytopathology* 66: 457-460.
- Lacki, M. J., and R. A. Lancia. 1983. Changes in soil properties of forest rooted by wild boar. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 37: 228-236.
- Lacki, M. J., and R. A. Lancia. 1986. Effects of wild pigs on beech growth in Great Smoky Mountains National Park. *Journal of Wildlife Management* 50(4): 655-659.
- Layne, J. N. 1997. Nonindigenous mammals. Pages 157-186 in Simberloff, D., Schmitz, D. C., and Brown, T. C., editors. *Strangers in paradise*. Island Press, Washington, D. C., USA.
- Leaper R., G. Massei, M. L. Gorman, and R. Aspinall. 1999. The feasibility of re-introducing wild boar (*Sus scrofa*) to Scotland. *Mammal Review* 29: 239-259.
- Lewis, T. E., D. Atencio, R. Butgereit, S. M. Shea, K. Watson. 1996. Sea turtle nesting and management in northwest Florida. Pages 162-164 in *Proceedings of the fifteenth annual workshop on sea turtle biology and conservation*. Keinath, J. A., D. E. Bernard, J. A. Musick, and B. A. Bell, editors. NOAA Technical Memorandum NMFS-SEFSC-387, Springfield, VA, USA.
- Lipscomb, D. 1989. Impacts of feral hogs on longleaf pine regeneration. *Southern Journal of Applied Forestry* 13: 177-181.
- Mackey, W. 1992. A survey on wild hogs of the United States. Minnesota Board of Animal Health, Minneapolis, MN, USA.
- Maehr, D. S, R. C. Belden, E. D. Land, and L. Wilkins. 1990. Food habits of panthers in southwest Florida. *Journal of Wildlife Management* 54: 420-423.
- Mason, R. J., and P. J. Fleming. 1999. Serological survey for *Brucella* antibodies in feral pigs from eastern Australia. *Australian Veterinary Journal* 77: 331-332.
- Mayer, J. J., and I. L. Brisbin. 1991. Wild pigs in the United States. University of Georgia Press, Athens, GA, USA.
- Mayer, J. J., and P. N. Brandt. 1982. Identity, distribution, and natural history of the peccaries, *Tayassuidae*. in M. A. Mares and H. H. Genoways, editors. *Mammalian biology in South America*. Special Publication Service. Volume 6. University of Pittsburgh, Pittsburgh, PA, USA.
- Mayer, J. J., and R. M. Wetzel. 1986. *Catagonus wagneri*. *Mammalian Species* 259: 1-5.
- McKnight, T. 1964. *Feral Livestock in Anglo-America*. University of California Publisher of Geology Number 16. Berkley, CA, USA.
- Moule, G. R. 1954. Observations on mortality amongst lambs in Queensland. *Australian Veterinary Journal*. 30: 153-171.
- Mungall, E. C. 2001. Exotics. 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, NJ, USA.
- National Agricultural Statistics Service (NASS). 1991. Sheep and goat predator loss. USDA, Agricultural Statistics Board, Washington, D. C., USA.
- Nature Conservancy. 1996. America's least wanted: Alien species invasions of U.S. ecosystems. The Nature Conservancy, Arlington, VA, USA.
- Nettles, V. F. 1997. Feral swine: Where we've been, where we're going. Pages 1-4 in K. L. Schmitz, editor. *Proceedings National Feral Swine Symposium*. USDA APHIS Veterinary Services, Riverdale, MD, USA.
- Nichols, L., Jr. 1962. Ecology of the wild pig. Federal Aid in Wildlife Restoration Final Report Project W-5-R-13. Hawaii Department of Land and Natural Resources, Division of Fish and Game, Honolulu, HI, USA.
- Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. *Wildlife Monographs* 62:1-135.
- Pavlov, P. M., R. J. Kilgour, and H. Pederson. 1981. Predation by feral pigs on merino lambs at Nyngan, New South Wales. *Australian Journal of Experimental Agriculture and Animal Husbandry* 21: 570-574.
- Pavlov, P. M., and J. Hone. 1982. The behaviour of feral pigs, *Sus scrofa*, in flocks of lambing ewes. *Australian Wildlife Research* 9: 101-109.
- Pearson, E. W. 1986. A literature review of livestock losses to predators in western U.S. U.S. Fish and Wildlife Service. Final Report, Denver, CO, USA.
- Pech, R. P., and J. Hone. 1988. A model of the dynamics and control of an outbreak of foot and mouth disease in feral pigs in Australia. *Journal of Applied Ecology* 25: 63-77.
- Pech, R. P., and J. C. McIlroy. 1990. A model of the velocity of advance of foot-and-mouth disease in feral pigs. *Journal of Applied Ecology* 27: 635-650.
- Pimentel, D., S. McNair, J. Janecka, J. Wightman, C. Simmonds, C. O'Connell, E. Wong, L. Russel, J. Zern, T. Aquino, and T. Tsomondo. 2000. Economic and environmental threats

- of alien plant, animal, and microbe invasions. *Agriculture Ecosystems and Environment* 84: 1-20.
- Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2002. Environmental and economic costs associated with non-indigenous species in the United States. Pages 285-303 in D. Pimentel, editor. *Biological Invasions: Economic and environmental costs of alien plant, animal, and microbe species*. CRC Press, Boca Raton, FL, USA.
- Plant, J. W., R. Marchant, T. D. Mitchell, and J. R. Giles. 1978. Neonatal lamb losses due to feral pig predation. *Australian Veterinary Journal* 54: 426-429.
- Rary, J. M., V. G. Henry, G. H. Matschke, and R. L. Murphree. 1968. The cytogenetics of swine in the Tellico Wildlife Management Area, Tennessee. *Journal of Heredity* 59: 201-204.
- Rollins, D. 1993. Statewide attitude survey on feral hogs in Texas. Pages 1-8 in C. W. Hanselka and J. F. Cadenhead, editors. *Feral swine: A compendium for resource managers*. Texas Agricultural Extension Service, Kerrville, TX, USA.
- Roots, C. 1976. *Animal Invaders*. Universe Books, New York, NY, USA.
- Rowley, I. 1970. Lamb predation in Australia: Incidence, predisposing conditions and identification of wounds. *CSIRO Wildlife Research* 15: 79-123.
- Saunders, G., and H. Bryant. 1987. The evaluation of a feral pig eradication program during a simulated exotic disease outbreak. *Australian Wildlife Research* 15: 73-81.
- Scrivner, J. H., D. A. Wade, G. E. Connolly, and L. C. Howard, Jr. 1985. The effects of predation on an Angora goat ranch. *National Wool Grower* 75: 10-13.
- 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.
- Smith, C. W., and C. H. Diong. 1977. Proposal to study feral pigs in Kipahulu Valley of Haleakala National Park. Technical report number 19. Cooperative National Park Resources Unit, University of Hawaii, Honolulu, HI, USA.
- Southeastern Cooperative Wildlife Disease Study. 1994. Wild swine behind fence. *SCWDS Briefs* 10:2 Athens, GA, USA.
- Stancyk, S. E. 1982. Non-human predators of sea turtles and their control. Pages 139-152 in *Biology and conservation of sea turtles*. K. A. Bjornadal, editor. Smithsonian Institution Press, Washington, D.C., USA.
- Stone, C. P., and J. O. Keith. 1987. Control of feral ungulates and small mammals in Hawaii's National Parks: Research and management strategies. Pages 277-287 in C. G. H. Richards and T. Y. Ku, editors. *Control of mammal pests*. Taylor and Francis, London.
- Stone, C. P., L. L. Loope, and C. W. Smith. 1988. Conservation biology in the Galapagos archipelago: Perspectives from Hawaii. *Elepaio* 48: 1-8.
- Synatzske, D. R. 1979. Status of the feral hog in Texas. Texas Parks and Wildlife Department, Artesia Wells, TX, USA. 9 pp.
- Tate, J., editor. 1984. Techniques for controlling wild hogs in the Great Smoky Mountains National Park. Proceedings of a workshop, November 29-30, Research/Resources Management Report SRE-72. U.S. Department of the Interior, National Park Service, Southeast Regional Office, Atlanta, GA, USA.
- Taylor, R. B., E. C. Hellgren, T. M. Gabor, and L. M. Ilse. 1998. Reproduction of feral pigs in southern Texas. *Journal of Mammalogy* 79: 1325-1331.
- Tisdell, C. A. 1982. Wild pigs: Environmental pest or economic resource? Pergamon Press, New York, NY, USA.
- Tisdell, C. A. 1991. The Australian feral pig and the economics of its management. Pages 155-170 in R. H. Barrett and F. Spitz, editors. *Biology of Suidae*. Biologie des Suides. I.R.G.M., Toulouse, France.
- Tolleson, D., D. Rollins, W. Pinchak, M. Ivy, and A. Hierman. 1993. Impact of feral hogs on ground-nesting gamebirds. Pages 76-83 in C. W. Hanselka and J. F. Cadenhead, editors. *Feral swine: A compendium for resource managers*. Texas Agricultural Extension Service, Kerrville, TX, USA.
- Towne, C. W., and E. N. Wentworth. 1950. Pigs from cave to cornbelt. University of Oklahoma Press, Norman, OK, USA.
- USDA. 2002. Environmental assessment: Management of predation losses to state and federally endangered, threatened, and species of special concern; and feral hog management to protect other state and federally endangered, threatened, and species of special concern, and candidate species of fauna and flora in the state of Florida. United States Department of Agriculture, Animal Plant and Health Inspection Service, Wildlife Services, Gainesville, FL, USA.
- Wade, D. A., and J. E. Bowns. 1985. Procedures for evaluating predation on livestock and wildlife. Bulletin Number B-1429, Texas Agricultural Extension Service, Texas A&M University, San Angelo, TX, USA.
- Wilcove, D. S., D. Rothstein, J. Bubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. *BioScience* 48: 607-615.
- Williams, E. S., and I. K. Barker. 2001. *Infectious diseases of wild mammals*. Iowa State University Press, Ames, IA, USA.
- Witmer, G. W., R. B. Sanders, and A. C. Taft. 2004. Feral swine — are they a disease threat to livestock in the United States? Eastern Wildlife Damage Management Conference 10: In press.
- Wood, G. W., and R. H. Barrett. 1979. Status of wild pigs in the United States. *Wildlife Society Bulletin* 7: 237-246.
- Wood, G. W., and T. E. Lynn, Jr. 1977. Wild hogs in southern forests. *Southern Journal of Applied Forestry* 1: 12-17.
- 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.