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# Overview of Impacts of Feral and Introduced Ungulates on the Environment in the Eastern United States and Caribbean

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**OVERVIEW OF IMPACTS OF FERAL AND INTRODUCED UNGULATES ON THE ENVIRONMENT IN THE EASTERN UNITED STATES AND CARIBBEAN**

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***Abstract:*** Non-native wild and feral ungulates have been introduced throughout the world for many centuries. Often the reasons for introductions were narrow in scope and benefits or the ungulates escaped or were released. Justifications for some introductions have included providing hunting opportunity, meeting cultural and dietary needs of people, fund raising, and aesthetics. Evaluations about the impacts to the environment, native wildlife, livestock, and people were most likely looked at in a narrow prism or not fully evaluated. Ungulates commonly introduced in the Eastern United States and Caribbean islands over the last 150 years included white-tailed deer, sika deer, hogs, horses, goats, and donkeys. Introductions have resulted in harm to endemic vegetation, competition with native herbivores for food, safety hazards to humans, disease threats to farm livestock and native wildlife, crop damage, and predation on eggs and young of native species. Some introductions provide significant positive economic benefits to local communities and present a unique set of resource and social challenges for the resource manager. Social and economic considerations may preclude removal as a management option. Once problems are recognized, management options can be assessed. However, the cost and effort of eradicating or suppressing non-native and feral ungulate populations can be daunting. Scarcity of funding can limit the scope and ability to remove enough of the animals to result in long-term benefits. Also, once substantial population reduction of undesirable animals is achieved, support for continued management may decline as recognition of the problem fades. An integration of control methods and some support from the local people are required to achieve removal of non-native and feral ungulates. Various challenges need to be addressed for control or eradication methods and strategies to be successful.

***Key words:*** eradication, feral ungulates, hoofed animals, introduced wildlife, invasive species, wildlife management

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**INTRODUCTION**

A feral animal is a formerly domesticated species that has reverted to a wild state (Van Vuren 1992). Non-native ungulates are those that have become established outside their natural range. Feral and non-native ungulates include deer (*Cervidae*), goats (*Capra hircus*), pigs (*Sus scrofa*), horses (*Equus callabus*), sheep (*Ovis aries*), and many other species. Long (2003) listed about 86 species of ungulates that have been introduced to various parts of the world. However, Teer (2003) reported that 124 species or "varieties" of ungulates have been introduced to Texas alone. Their populations can be established several ways (Long 2003). Feral ungulates can be intentionally introduced for agricultural purposes or for recreational hunting (De Vos et al. 1956, Wood and Barrett 1979, Gipson et al. 1998, Martin 2005), for personal objectives (Miller 1993), or so that a supply of meat is readily available (Mayer and Brisbin 1991, Van Vuren 1992). Some ungulates may escape from farms and establish feral populations (Stegeman 1938, De Vos et al. 1956). Some populations of ungulates have been established for no known reason. Also, populations of non-native ungulates may be allowed to persist due to their aesthetic value, hunting, food, income, or prohibitive cost to eradicate.

The introduction of non-native or feral ungulates to non-indigenous ecosystems may result in economic or ecological harm or threaten human and animal health (Long 2003, Teer 2003). Domestic or wild animal health may be harmed by the introduction of non-native ungulates that may be carrying disease agents which may infect domestic or wild animals, and harm commerce. Non-indigenous species in the U. S. cause major environmental damage and losses costing more than $138 billion annually (Pimentel et al. 2002). In the U.S., about 42% of listed threatened or endangered species are at risk primarily due to non-indigenous species (Pimentel et al. 2002). The International Union for Nature included feral pigs, feral goats, and red deer (*Cervus elaphus*) on their list of the "100 of the World's Worst Invasive Alien Species" (Lowe et al. 2004). The book edited by Pimental (2002) contains chapters on introductions in Australia, New Zealand, the United Kingdom, and the United States. Other recent reviews cover deer introductions in Australia (Moriarty 2004), non-native large mammal introductions in North America (Teer 2003), and mammal introductions in New Zealand (Parkes and Murphy 2003).

**Economic and Ecological Considerations**

In 1988, feral swine populations were reported in 19 states, primarily in the southeastern United States and California (Mayer and Brisbin 1991), but Miller (1993) reported that feral hogs were now found in 23 states and their range was expanding. Feral hogs have an omnivorous diet comprised of mostly plant material (grasses, forbs, fruit, nuts, tubers, seeds, and shoots), but also a variety of invertebrates and vertebrates, including fawns, livestock, rodents, frogs, and other wildlife (Peine and Farmer 1990, Seward et al. 2004).

Feral swine activities may seriously impact agricultural systems, especially crops and livestock (Ensminger 1961, Donkin 1985, Stinger et al. 1982, Seward et al. 2004). Feral swine damage $800 million in agricultural crops each year in the United States (Pimentel et al. 2002). Forty of 58 county agricultural commissioners in California reported $1.7 million in feral swine damage to agriculture (Frederick 1998). In Australia, livestock predation by feral swine has been estimated at over $100 million in losses each year (Choquenot et al. 1996).

Where feral swine occur in sizeable densities they have been implicated in losses to native flora and fauna, soil erosion, declines in water quality, reforestation damage, and reduced biodiversity (Wood and Barrett 1979, Witmer et al. 2003b., Engeman et al. 2003). Widely introduced, feral pigs have contributed to declines and extinctions of numerous species on oceanic islands and can have pronounced negative ecological effects on mainland areas when populations are high (Waithman et al. 1999). Peine and Farmer (1990) summarized ecological damage to Great Smoky Mountain National Park as greater than a 95% reduction in herbaceous understory in beech (*Fagus grandifolia*) forests, reduction in mature and flowering non-woody plants, changes in plant species composition, predation on a potentially threatened salamander and a snail, an estimated 80% reduction in micro-invertebrates in the soil, siltation and contamination of streams, and predation on native grouse and turkey nests. Soil erosion, accelerated with feral swine rooting activities, resulted in leaching of minerals from the leaf litter and soil (Peine and Farmer 1990), sets back plant succession, and exacerbates exotic plant invasion (Mungall 2001).

Engeman et al. (2003) reported feral hogs adversely affected basin marshes in Florida. The area of one marsh damaged (e.g., rooting and foraging) was valued between $1.2 and $4.0 million dollars, based on amounts wetland regulators allow wetland permit applicants to spend in mitigation attempts.

Feral goats cause severe damage to island natural resources (Van Vuren 1992, Keegan et al. 1994, Parkes et al. 1996). Damage includes large scale alteration of plant communities, negative impacts on insular endemic species of plants and animals, and damage to soils. The principle impact is damage to vegetation which results in alteration of the plant communities and cascades into impacts on soils and animals that depend on unaltered plant communities for habitat (Van Vuren and Coblentz 1987). Protection of insular ecosystems is probably impossible without eradication of feral goats (Vitousek 1988). Endemic biota on San Clemente Island, California has been severely degraded by feral goats (Keegan et al. 1994). Four plants, two birds, and one reptile species endemic to San Clemente Island have been listed under the Endangered Species Act (U.S. Navy 1979) and an additional 24 plants and 5 animals have been considered for listing (U.S. Navy 1981). It has been estimated that the eradication of feral goats on Isabela Island (Galapagos Islands) will cost about $8.5 million and require about 6 years to complete (Galapagos Conservation Trust website: www.gct.org/isabela1.html). In Australia, feral goats cause an estimated $18 million dollars in agricultural crop losses each year, but also bring in about $4 million in revenues to those that harvest and sell feral goat meat (Parkes et al. 1996).

White-tailed deer (*Odocoileus virginianus*) and sika deer (*Cervus nippon*) have caused damage to plant communities, agricultural crops, and forest resources when introduced to non-native environments (Long 2003). This damage has been most pronounced on islands. White-tailed deer have been introduced throughout the Caribbean islands from the United States, Mexico, and South America for hunting (De Vos et al. 1956). They were introduced to Cuba in the 1850's from the southeastern United States (De Vos et al. 1956). Also, white-tailed deer from Florida were introduced onto Guantanamo Bay Naval Station for hunting about 1954 (Capt. Dupree, U.S. Marine Corps, pers. commun.). Sika deer were introduced to Assateague Island, Maryland in 1923.

Feral horses and burros (*Equus asinus*) have become established in many parts of the world; in the U.S., they occur in several western states and on several barrier islands along the east coast (Jenkins and Ashley 2003, Long 2003). They compete with livestock and native ungulates for forage and can damage habitats, especially at water sources (Jenkins and Ashley 2003, Long 2003). Feral horses on Assateague Island, Maryland, were reported by National Park Service officials to be causing damage to natural grasses and dunes (Associated Press 2005). The damage the 160 feral horses do to the ecosystem is apparent. Feral horses grazed and trampled vegetation on Cumberland Island National Seashore, Georgia, and reduced plant biomass up to 55% (Turner 1986). The impacts of grazing on the salt marsh were stronger as above ground vegetation was reduced up to 98% by feral horses (Turner 1986). Pimental et al. (2002) estimated that feral horses and burros in the U.S. cause about $5 million in damages each year. Additionally, operation of the federal Wild Horse and Burro Program (consisting mainly of the Adopt-a-Horse-or-Burro Program) costs about $20 million per year (Jenkins and Ashley 2003).

While the eradication of non-native or feral ungulates may seem a logical solution to the ecological and economic problems that they cause, one must consider the unexpected ecological responses that can result from such management actions. For example, invasive plants may gain a greater foothold in plant communities once feral sheep (Klinger et al. 2002) or feral goats (Bullock et al. 2002) are removed. In another example, Golden eagles (*Aquila chrysaetos*) began using the Northern Channel Islands of California, in part because of the prey base that introduced feral pigs provided. Unfortunately, with control of the feral pigs, the eagles have preyed more heavily on the endangered island fox (*Urocyon littoralis*)(Roemer and Donlan 2004).

### Human and Animal Health

Feral swine are a reservoir of at least 30 significant viral and bacteriological diseases (Williams and Barker 2001) and there is a concern regarding the role feral swine may have in an outbreak of a foreign animal disease (e.g., foot-and-mouth disease) (Witmer et al. 2003b). The highly infectious diseases pseudorabies and swine brucellosis are considered threats to the commercial pork industry (Witmer et al. 2003a). Feral swine in Florida have been documented to have as many as 45 different parasites and infectious diseases (Forrester 1991). Feral swine in California were found positive for brucellosis at 3 of 28 sites where they were tested (Sweitzer et al. 1996). Brucellosis is transmissible to man (Seigmond 1973). Other feral pigs in California have tested positive for pseudorabies (Sweitzer et al. 1996). Ungulates and livestock may also serve as reservoirs of bovine tuberculosis and leptospirosis, two other diseases transmissible to humans (Witmer et al. 2003a, 2004). The potential for exposure to zoonotic disease in people from feral pigs is of concern because hunters and others regularly handle and consume feral swine. Sanitary handling and cooking of wild swine are important due to concern for trichinellosis, toxoplasmosis, and sylvatic plague which has been found in feral pigs in California (Sweitzer et al. 1996).

The translocation of captive cervids in the U.S. has facilitated the distribution of chronic wasting disease to several states (Miller and Williams 2003). The potential impact of this emerging disease on native ungulate populations has resulted in restrictions or bans in several states on the transport and keeping of captive deer and elk.

## CASE HISTORIES

### White-tailed Deer and Feral Goats at Guantanamo Bay, Cuba

The U.S. Naval Base Guantanamo Bay, Cuba (GTMO) occupies approximately 29,000 acres including 9,000 acres of open water. The base is located in the Guantanamo Province near the southeastern tip of Cuba. The area is considered tropical desert/dry forest habitat due to its location in the rain shadows of the Sierra Cristal and Sierra Maestra Mountians. Average annual rainfall is less than 20 in per year and precipitation normally occurs in heavy downpours in two short “rain seasons”, generally once in May and again in October-November. As such, the area supports some very unique, rare, and endemic flora and fauna. A Rapid Ecological Assessment (REA) of GTMO conducted by the Nature Conservancy in 1999 identified 70 plant species endemic to the Antilles including 51 species endemic to Cuba and four endemic to GTMO and the associated dry forest of the Guantanamo Province (Roca and Sedaghatkish 1998). The REA further identified a large number of animal species endemic to Cuba: 21 species of reptiles and amphibians, 8 species of birds, and 4 species of mammals endemic to the Caribbean. This high rate of endemism is characteristic of island biogeography and amplified at GTMO by the somewhat unique climate and associated ecotypes found here.

Unfortunately, the magnificent floral biodiversity of GTMO, that accounts for 1.7% of the Caribbean flora, is currently under great stress because of over-grazing by populations of feral goats, introduced white-tailed deer and high densities of the native rodent, hutia (*Capromys pilorides)* (Areces-Mallea 2000). The overgrazing has gone beyond the limits of self-sustainability of most extant terrestrial ecosystems with plant communities loosing their original richness and density at an unprecedented rate (Areces-Mallea 2000).

The ecological impact of intensive browsing and defoliation of this ecosystem from feral goats and introduced deer is amplified when combined with excessive herbivory from the overly abundant population of the herbivorous hutia. While habitat degradation from feral goats and deer impacts vegetation from the forest floor to a browse line at about 1.5-2 m, excessive numbers of hutia have adverse impacts to all vegetation, including cacti and the dry forest canopy. The direct impacts from excessive overgrazing on native flora are somewhat obvious, but there are also impacts to coral reef habitats from accelerated rates of erosion and sedimentation into receiving waters when vegetated buffers are degraded or completely denuded.

There are also indirect impacts on native fauna as their habitats become degraded. For example, the goats and deer are competing for food with the endemic, federally-threatened Cuban ground iguana (*Cyclura nubilus*) (Roca and Sedaghatkish 1998). Wide-scale habitat defoliation has resulted in iguanas moving over larger areas in search of food and shelter. The increased movements through denuded habitats subjected iguanas to higher levels of mortality than what normally occurs when iguanas occupy a territory within adequate habitat. In addition, dispersal has subjected juvenile iguanas to increased mortality while searching for adequate habitat in which to establish a home range. Iguana mortality factors include natural predation from snakes and raptors, but also anthropogenic causes such as predation from feral cats (*Felis catus*), feral dogs (*Canis familiaris*), and feral chickens (*Gallus gallus*), vehicle strikes, and illegal collection for food or economic gain.

In addition, excessive numbers of goats and deer have presented other problems such as aircraft and vehicle strike hazards. There have been numerous collisions with vehicles, resulting in damage to government and privately-owned vehicles. Residents have also complained of damage to the landscaping of their yards as goats and deer ventured into residential areas.

While deer were brought to GTMO for recreational hunting, at some point in the mid- to late-1980s, recreational hunting was stopped on the base. Goats were initially used as livestock. Privatization of the labor force resulted in an influx of persons from other countries with little interest in raising goats. Subsequently, the animals were released or escaped from captivity. Because there are virtually no predators for these species at GTMO, goat and deer populations grew unchecked.

Non-native and feral ungulate control at GTMO began in 2001, targeting the overly abundant goats and deer, but included other invasive species (feral cats, feral dogs, feral chickens, pigeons (*Columba livia*), and helmeted guinea fowl (*Numida meleagris*) and management of high densities of native hutia. Forsyth et al. (2000) argued the case for multiple introduced herbivorous species management to increase efficiency and effectiveness. The base established a permanent Natural Resources Manager position to manage these feral animals as part of a comprehensive Natural Resources Conservation Program. Management efforts resulted in significant reductions in invasive species populations and acceptable densities of native hutia. Between 2001-2004, about 121 goats and 750 deer were removed from GTMO. Both day and night shooting from foot and vehicles were employed in the control effort. The subsequent eradication of feral goats and substantial reduction of deer resulted in habitat recovery and subsequent observations of larger numbers of species targeted for conservation such as iguanas, especially juvenile iguanas, and other smaller iguanid-type lizards of Cuba. Although difficult and cost prohibitive to quantify, these cursory observations were also noted by several cooperating biologists from different agencies and organizations who routinely visit GTMO on recurring projects.

Continued support from officials in decision-making capacities is vital to successful wildlife damage management and invasive species control and eradication. The success of the invasive species control operation is heavily dependent on funding, requiring about $92,500 annually. These programs must be in continuous operation unless substituted with recreational hunting or the target invasive species will recover and high damage levels will return. Therefore, ongoing and continued support is considered a management priority requiring education and outreach efforts towards those who authorize and fund these programs. In some cases, research is conducted to support management decisions and operational methods.

There are many factors influencing decisions made relative to the control program at GTMO. One consistent problem at military facilities is the rapid turnover rate of personnel, including those in high-level decision-making capacities. As control programs progress, the target species is no longer perceived as a problem and when personnel transfer into a given facility, they have little or no working knowledge of the history or accomplishments of the existing control program. Often, they perceive this function as unnecessary in spite of educational and outreach attempts. The decision may also be influenced by local special interest groups opposed to controlling animal populations, especially when numbers have been reduced to where the population is not considered a problem. In this case, low density and healthy populations of deer, for example, occupying recovered habitat can reach their full reproductive potential with irruptive growth in the population. The population numbers quickly rebound to problematic levels and, as is often the case, those responsible for curtailing control activities have since transferred to a different facility.

**Feral Horses and Sika Deer at Chincoteague National Wildlife Refuge (NWR), Virginia**

Chincoteague NWR, located primarily on the Virginia portion of Assateague Island and including Chincoteague Island, consists of more than 14,000 ac of beach, dunes, marsh, and maritime forest. The refuge was established in 1943 to provide habitat for migratory birds. More than 320 species of birds are known to occur on the refuge. The refuge has been designated a Globally Important Bird Area, is part of the Western Hemisphere Shorebird Reserve Network and designated as one of the top ten birding Hotspots by the National Audubon Society (see Refuge website: [www.fws.gov/northeast/chinco](www.fws.gov/northeast/chinco)). Refuge management programs restore threatened and endangered species such as the Delmarva Peninsula fox squirrel (*Sciurus niger cinereus*), the bald eagle (*Haliaeetus leucocephalus*) and the piping plover (*Charadrius melodus*). More than 2,600 ac of man-made marshes, or moist soil management units, are managed for wintering waterfowl and shorebirds during migration. With about 1.4 million visits a year, Chincoteague NWR is one of the most visited refuges in the nation.

Assateague Island is a barrier island extending north and south with Atlantic Ocean to the east and the mainland to the west. The Island has beaches, dunes, grassy areas, shrub areas, marshes, and forests consisting of loblolly pine (*Pinus taeda*) and some hardwood species. The refuge also contains manmade freshwater areas that cover 2,623 ac and provide submergent and emergent wetland vegetation for wildlife. Salt marsh areas are found between Assateague Island and Chincoteague Island and the mainland.

White-tailed deer are the only native ungulate found on Chincoteague NWR and the rest of Assateague Island. Since the arrival of Europeans two other ungulates, feral horses and sika deer, were introduced to the islands. Over time, sika deer have entirely colonized Assateague Islands.

While popular folklore would like the Chincoteague "pony" to be descendants of survivors of shipwrecked Spanish galleon, more likely the horses are feral ancestors of stock grazed to avoid fencing regulations and taxation. Early settlers quickly recognized the abundant forage resources of Virginia's barrier islands and stocked the islands with horses, cattle (*Bos taurus*), and sheep. The islands required no fencing and their remoteness precluded any supervision by the tax assessor. In 1671, Colonel Daniel Jenifer attained a land grant on Assateague Island allowing him to graze his livestock and avoid the mainland fencing ordinance and the mainland tax assessor. In 1808, George Washington Parke Custis, step-grandson of George Washington, advocated the value of raising sheep on the islands. Penning began for livestock owners to claim, brand, break, and harness their loose herds. In 1835, Thompson Holmes described the annual horse penning on Chincoteague Island and indicated the practice had occurred at least 30 years prior.

A fence along the Virginia/Maryland State line (the northern refuge boundary) separates the island's feral horses into two herds. The National Park Service (NPS), Assateague Island National Seashore, manages the Maryland herd. The Virginia herd is owned by the Chincoteague Volunteer Fire Company and is grazed in two pastures. Horses have been allowed to roam freely on the refuge, but resource damage to the dune system and conflicts with refuge visitors and vehicles resulted in confinement to pastures. Chincoteague NWR horse numbers are maintained at 150 adults; foals are sold each year during "pony" penning. The Maryland herd is regulated by immuno-contraceptives with a population objective of 100-125 horses. In 1947, Marguerite Henry published "Misty of Chincoteague," the story that immortalized Chincoteague “ponies” and made the horses internationally famous. “Pony” penning occurs in July and 40,000 to 50,000 visitors are attracted to Chincoteague Island to view the penning and foal auction. “Pony Auction” revenues provide revenue for the fire company.

Sika deer, native to eastern Asia, have been introduced to many parts of the world (Long 2003). In the early 1900’s, Clemment Henry of Cambridge, Maryland, obtained a small herd of sika deer from an unknown source. In 1916, he released a number of deer on James Island that eventually became the source of sika deer on the Maryland mainland. Dr. Charles Law of Berlin, Maryland, purchased a number of deer, most likely from Mr. Henry. Those deer were either sold to an individual who later released them on Assateague Island or were obtained by the Boy Scouts who operated a petting zoo at Ocean City, Maryland, and later released them on Assateague Island. Regardless, sika deer found the island to their liking and have been present since the early 1920’s. Sika deer compete better than white-tailed deer for food resources on Assateague Island, resulting in an apparent decline in native deer (Keiper 1985). Hunting programs for Sika deer occur on Chincoteague NWR and on NPS lands. Approximately 400-500 deer are taken yearly on Assateague Island. The sika deer population is managed through hunting to prevent damage to native flora and to limit competition for food resources with native wildlife.

## METHODS OF CONTROL

Methods of control available to remove or eradicate non-native and feral ungulates include monitoring and surveillance methods and control methods. For effective control or eradication, the use of multiple methods is usually required (Schuyler et al. 2002, Butchko et al. 2003). Methods currently available to remove non-native ungulates were summarized by Van Vuren (1992), Barrett and Biringham (1994), Choquenot et al. (1996), Parkes et el. (1996) and McCann et al. (2004). Of course, the costs and effectiveness vary considerably among the methods (Choquenot et al. 1996). The application of benefit-cost analyses can help in deciding on which method(s) to use and whether or not control is warranted (Schwiff 2004). Research continues to improve existing methods and to develop new methods.

### Monitoring and Surveillance

Monitoring and surveillance are important components of an effective non-native ungulate management program (Butchko et al. 2003, Peine and Farmer 1990, Choquenot et al. 1996, Parkes et al. 1996). Monitoring and surveillance are necessary to establish locations used by target species, develop baseline populations for target species, and measure efficacy of removal efforts of non-native ungulate.

A conundrum of monitoring and surveillance is detecting remnant survivors after control or newly-arrived individuals. Survivors tend to be low in abundance, dispersed, and wary. Several methods have evolved to detect remnant populations including aerial surveys by helicopter, use of detection dogs, snow or sand tracking, cameras at bait or water stations, systematic sweeps of areas, and “Judas” goats. Judas goats are animals that are captured and fit with radio collars. The collared animal is released and allowed to return to other remnant individuals. This method works well with social ungulates (Taylor and Katahira 1988).

### Sterilization of Feral Horses

Sterilization has been used as a means of controlling feral horse populations for a number of years (Kirkpatrick et al. 1997). Sterilizing males is not effective for many ungulate species because of the polygamous mating system of sheep, goats, deer, and hogs. However, sterilization can be effective for horses because the fertility of an entire herd could be controlled through the treatment of a single stallion (Warren et al. 1997). Disadvantages of sterilization include immobilization cost, surgery requirements, and dangerous, hard work required (Warren et al. 1997). Of course, an additional requirement is the sterilization of each successive stallion that takes over the harem (Slade and Godfrey 1982). Sterilization would be less effective in herds having sexual mature subordinate stallions or a high degree of movement by mares between harems (Warren et al. 1997).

**Trapping**

Trapping has removed tens of thousands of feral goats and sheep from islands (Van Vuren 1992). Traps have also been used extensively for feral pigs, deer and horses. Trapping can be logistically difficult and will not lead to eradication since some ungulates will be "trap-shy" and elude capture (Van Vuren 1992). Both single-animal and multiple-capture traps have been used and many designs are available (Barrett and Birmingham 1994, Schemnitz 1994, Choquenot et al. 1996, Parkes et el. 1996). The use of radio-transmitters on remote traps can improve efficiency by allowing personnel to determine, from a distance, that a trap has been triggered (McCann et al. 2004).

Trapping wild pigs is labor intensive. Cage trapping was the most effective method to remove feral pigs and accounted for 75-80% of the pigs killed each year (Richardson et al. 1997). Trapping success may be contingent on pre-baiting, free-baiting, and good trap design (Sweitzer et al. 1996, McCann et al. 2004). Although feral pigs will eat a wide variety of baits, they tend to prefer fermented corn or corn-based commercial pig feed (McCann et al. 2004).

Feral pigs may be effectively snared in trails (Richardson et al. 1997), especially when snares are placed in trails on the way to bait piles. All hunting or other human disturbance should cease once trapping begins because increased human activity often results in feral pigs moving to other areas (Richardson et al. 1997). Deer are also susceptible to being snared along trails.

Rocket nets or drop nets are two types of nets regularly used to capture deer and other ungulates (Connor et al. 1987, Schemnitz 1994). Ungulates are vulnerable to being captured by nets propelled or dropped over feeding individuals. Ungulates can be effectively baited in with high-energy foods, such as corn, during the winter months when natural foods are scarce. Feral pigs are also vulnerable to this technique.

**Shooting from the Ground**

Shooting from the ground has proven to be a very effective technique (Van Vuren 1992, McCann et al. 2004). Biologists and technicians working in teams can kill large numbers of non-native or feral ungulates quickly and economically (Van Vuren 1992). Most successful goat and sheep eradication programs have been achieved by shooting from the ground. Shooting can be conducted during day or night hours, and shooting over bait often increases effectiveness.

Shooting is one of the more effective methods for reducing feral swine populations (Peine and Farmer 1990). Shooting pigs from the ground may be more effective with the use of dogs, especially when pigs are at low densities (McCann et al. 2004). Public hunting has also been used, although with only limited effectiveness, to control feral pig populations (Choquenot et al. 1996, Richardson et al. 1997).

The cost to eradicate deer by shooting ranges from $300-$963 per animal (Martin 2005, Butchko et al. 2003). While public hunting has been ineffective at eradicating deer, it has been effective at controlling deer populations when hunters are given adequate access to the area (Vercauteren and Hygnstrom 2000). The use of dogs to locate deer, and large numbers of people to drive deer from dense vegetation, can aid in deer removal efforts (Butchko et al. 2003).

**Shooting from the Air**

Shooting from helicopters is an extremely effective and rapid method of population control of large animals (Baker and Reeser 1972). However, it is very expensive and animals may learn to recognize the sound of the helicopter and hide (McCann et al. 2004). Helicopters can be a key component to removal or eradication of deer or other ungulates (Butchko et al. 2003). Helicopters are also valuable for transporting equipment and traps, getting personnel into remote locations, and for surveying areas for ungulates (McCann et al. 2004).

**Fencing**

Fencing can be an important component of control or eradication programs (McCann et al. 2004). Materials and installation, however, are very expensive and regular maintenance is required. Fencing may be used to partition the island into smaller parcels to facilitate eradication and to keep animals from returned to an area once it is cleared of ungulates (Butchko et al. 2003, Van Vuren 1992). VerCauteren et al. (IN PRESS) reviewed the many types, costs, and effectiveness of ungulate fencing. Horses, goats, and other ungulates can be rounded up---a process sometimes called mustering--- into fenced areas, using helicopters or by horseback (Parkes et al. 1996, Jenkins and Ashley 2003).

**Recent Technological Advances**

There have been technological advances in equipment that are useful in ungulate control and eradication. The use of forward-looking infrared (FLIR) thermal imagers, night vision goggles, and suppressed rifles are examples of technological advances that improve efficacy of ungulate removal programs. Belant and Seamans (2000) reported that FLIR detected more deer than spotlights and night vision goggles (825 versus 716 deer). In field tests conducted in Pennsylvania, FLIR detected up to 70% more deer in dense vegetation than spotlights (J. Suckow, pers. comm.). FLIR units can also be used from helicopters (McCann et al. 2004).

Suppressors reduce the report of the rifle when a bullet is discharged. The reduction in report appears to reduce the likelihood of deer fleeing. The reduced noise is alsp beneficial when conducting operations near inhabited areas. Suppressors are regulated by the Bureau of Alcohol, Tobacco, and Firearms and their availability is greatly restricted by statute. State and federal wildlife agencies are able to acquire necessary federal permits to use suppressors. States may also have restrictive regulatory requirements on the use of suppressors.

**Research on Methods Development**

Much research has been underway on fertility control of wildlife (e.g., Kirkpatrick et al. 1997). The issues and challenges of this method were reviewed by Fagerstone et al. (2002). Research has identified several materials that could effectively sterilize non-native and feral ungulates (Miller et al. 2004). Efficient delivery methods remain a major challenge with this method.

Turner and Turner (1991) reported 29 percent fertility in treated feral horse herds compared to 45% fertility in control herds when stallions were administered a microencapsulated form of testosterone propionate (MTP). Contraception would require annual treatments and would be less effective in herds having sexual mature subordinate stallions or a high degree of movement by mares between harems (Warren et al. 1997). Immuno-contraceptives have been used on wild horses (mares) to block ovulation for up to 3 years. The vaccine (porcine zona pellucida) was delivered remotely via darts, however, a booster shot was required to extend contraception a second year (Kirkpatrick et al. 1997). Improvements in fertility control for horses have been made (Killian et al. 2004). Fertility control research is also underway on feral swine (Killian et al. 2003).

Immuno-contraception used alone will not eradicate a population of non-native deer over time because it is virtually impossible to treat all, or even the vast majority, of the deer. The cost to contracept deer is about $3,000 per animal (Martin 2005). Fertility control would, at least theoretically, reduce habitat damage over the long period term by preventing population growth via mortality exceeding reproduction and survival. Because of the relatively long life span of most ungulates, however, the damage may continue for many years or even decades even though many animals are sterile. In one situation where immuno-contraception was used with a confined herd of wild deer, the population continued to increase in abundance even though deer continued to be killed by vehicles and male deer dispersed from their natal area (Naugle 2002). Fertility control research on deer continues (Miller et al. 2004).

Some novel approaches to non-native and feral ungulate control and eradication that are being investigated in other countries, but not in the U.S., include broad-casting of toxic baits (Forsyth and Parkes 1995, Lapidge et al. 2004 ), use of toxic pastes on foliage (Veltman and Parkes 2002), biological control via disease transmission (Choquenot et al. 1996, Pech 2000), and carnivore introduction (Parkes et al. 1996). Each of these approaches is not without serious disadvantages, including non-target hazards, and can only be used under very unique or specific circumstances (Choquenot et al. 1996).

## DISCUSSION AND MANAGEMENT IMPLICATIONS

Wildlife managers need to consider many types of information in the management of non-native and feral ungulates. There are at least four important questions that need to be answered prior to undertaking feral ungulate management for the project to succeed. These questions are 1) is eradication possible or should long-term control be implemented? 2) is there some support for eradication or control from local people? 3) do decision makers support funding for eradication or control? and 4) what are the economics of eradicating or controlling the ungulates?

Is eradication possible or should control be implemented? Bomford and O'Brien (1995) identified six criteria, three criteria that were critical, for eradication to be successful. The three critical criteria that must be met in the affirmative for eradication to be successful were 1) the rate of removal exceeds the rate of population increase for all population densities, 2) immigration is prevented, and 3) all reproductive animals must be at risk for removal. The other three criteria that are desirable for eradication to be successful are 4) animals must be detected at low densities, 5) discounted benefit-cost analysis favors eradication over control, and 6) a suitable socio-political environment exists.

We analyzed management options (eradication or control) for feral ungulates at GTMO and Chincoteague NWR using analyses described by Bomford and O'Brien (1995). The analyses concluded that at GTMO eradication of feral goats was achievable whereas eradication of deer was less clear because we were unable to say with certainty that immigration was prevented (Table 1). For Chincoteague NWR, we concluded that the management of feral horses was preferred to eradication due to benefit-cost analysis favoring management (Table 1). The initial analysis of management of sika deer appeared to favor eradication, however, additional benefit-cost analysis and socio-political environmental factors need further exploration (Table 1).

Support of local people for eradication or control is necessary to garner cooperation from landowners, advocacy groups, government agencies, and political leaders. The level of support for management actions should exceed 50% of the public. Realistically, the level of support will rarely exceed 85% of the public since about 3% of the public has animal rights values and 12% of the public has animal welfare values (Duda et al. 1998a, 1998b). While citizens with animal rights and animal welfare values may not support an eradication or control action, they may remain neutral if they feel the action is necessary and other reasonable means to resolve the human-animal conflict have been tried. The cooperation of landowners and the public is also essential so that access to all, or at least most, occupied areas can be had for control operations.

The support of decision-makers to provide funding for eradication or control is required when government agencies are involved. Decision-makers could include land managers, political appointees or leaders, or advocacy groups. This support may change over time for several reasons. Support may be high initially when the non-native or feral ungulate problem is most acute. However, as ungulates are removed from the environment and the level of damage declines, decision-makers may be drawn to other pressing issues. A continuous education effort is required to keep decision-makers, stakeholders, and the public informed of the need to manage the ungulates.

Do the economics of non-native or feral ungulates favor eradication or control? Sometimes these ungulates generate benefits that are unusually large or affect a small local economy at times of the year when other economic activity is low. Two examples of benefits that require careful analysis prior to implementing a non-native ungulate management action would be the feral horses and introduced sika deer on Chincoteague NWR. The Town of Chincoteague, Virginia, receives nearly $32 million dollars in annual non-consumptive use benefits from Chincoteague NWR (Caudill and Henderson 2003). Of these benefits, about $7.5 million are from bird watching (Lowney et al. 2005). The remaining $24 million in economic benefits are derived from the public using the beach (2/3 of visitors) and activities associated with watching the feral horses as well as the annual "pony" swim and auction. We estimate that the economic benefit associated with the feral horses may be as large as $8 million dollars, thus their management may be a more desirable management action than eradication (Table 1).

**Table 1. Analysis of criteria to determine whether eradication or control of non-native and feral ungulates are appropriate management actions at Guantanamo Bay Naval Station, Cuba, and Chincoteague National Wildlife Refuge, Virginia. Analyses follow criteria established by Bomford and O'Brien (1995).**

| Criteria | Guantanamo Bay | | Chincoteague | |
|---|---|---|---|---|
| | Goats | White-tailed deer | Horses | Sika deer |
| Rate of removal exceeds rate of increase | Yes | Yes | Yes | Yes |
| Immigration is prevented | Yes | ? | Yes | Yes |
| All reproductive animals at risk | Yes | Yes | Yes | Yes |
| Animals can be detected at low densities | Yes | Yes | Yes | Yes? |
| Benefit-cost analyses favors eradication over control | Yes | Yes? | No | Yes? |
| Suitable socio-political environment | Yes | Yes | No | No |

Sika deer are hunted by about 380 people on Chincoteague NWR each year during December and January. Hunting sika deer creates a $27,200 economic benefit for the Town of Chincoteague during winter months when other tourism activities are low (Caudill and Henderson 2003). Sika deer hunting provides a very small benefit (0.07 %) of the total $40.4 million dollar benefit that the refuge provides to the local economy. This small economic benefit is important to the local economy because of the time of year the benefit is accrued. This small benefit would need to be weighed against ecological costs and socio-political variables to determine the appropriate management action (Table 1).

In conclusion, various challenges need to be addressed for control methods to be successful. Adequate resources and methods must be available to reduce the numbers of, or eliminate, the problem ungulates. This includes adequate population monitoring, use of advanced technology, aerial operations, various traps, special shooting equipment, and highly skilled and dedicated wildlife specialists. Additional challenges include adequate monitoring of ungulate populations to measure progress, maintaining support of decision-makers who must approve funding, adequate funding to use costly control methodologies and to pay salary costs, and overcoming political obstacles from diverse advocacy groups that benefit from, or otherwise support, non-native ungulates.

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