August 2007

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Abstract: At least 161 introduced/invasive vertebrates have become established in the United States and its territories, including at least 81 mammalian, 94 avian, and 86 reptilian/amphibian species. Particularly problematic species include feral cats and dogs; feral pigs; commensal rats and mice; starlings, pigeons, and house sparrows; and bullfrogs, brown treesnakes, and coqui frogs. We briefly review these introductions and the types of damage they cause. We review the basic types of methods used for control or eradication of each taxonomic group, including physical, chemical, biological, and cultural methods. We also discuss some of the challenges in managing these species, including issues with the use of toxicants, land access, public attitudes, and monitoring difficulties. Finally, we discuss some ongoing research and future research needs, including fertility control, improved detection methods, improved attractants, improved barriers, improved capture methods, and risk assessment methods.

Key Words: animal damage, eradication, introduced species, invasive species, management.

Managing Vertebrate Invasive Species: Proceedings of an International Symposium (G. W. Witmer, W. C. Pitt, K. A. Fagerstone, Eds). USDA/APHIS/WS, National Wildlife Research Center, Fort Collins, CO. 2007.

INTRODUCTION

Vertebrate species have been introduced to almost all parts of the world for thousands of years. The large volume of worldwide trade and transportation have accelerated the rate of introductions in the last 150 years or so. Animals are introduced for many reasons, both purposeful and accidental. Purposeful introductions occur for food and fur, work animals, sport hunting and fishing, companion animals, aesthetics, and pest control. Accidental introductions occur because of stowaways in transport vehicles, released animals (without an original intent to release), escapees, and, in some cases, because of range expansion of a species (often facilitated by human activities and land uses).

While many introduced vertebrate species have provided important resources and economic gains for humans and many do not cause undue adverse effects (especially with appropriate management), some have increased their distribution and have caused serious adverse effects. These include disease and safety hazards, predation and competition with native species, crop consumption and contamination both in the field and during storage, livestock predation, and, in some cases, significant environmental degradation. Unfortunately, for many species of introduced vertebrates, we do not yet know if they are causing, or in the future will cause, significant harm to the environment or human resources. Hence, our use of the term "introduced/invasive" vertebrate spieces.

Lists of mammalian (Long 2003) and avian (Long 1981, Lever 1987) introductions around the world have been compiled with relatively minor discussion of impacts and control efforts. As political and social awareness has grown, efforts to assess introduced species and their adverse impacts have increased (Pimentel et al. 2005). A conference held in New Zealand in 2001 brought attention to the widespread problems with invasive species and illustrated many of the diverse projects being conducted around the world to try to resolve some of the situations (Veitch and Clout 2002). Witmer and Lewis (2001) reviewed vertebrate introductions in the Pacific Northwestern Region of the United States (US), the resultant impacts, state and federal legislation, management methods and strategies, and some case studies for birds, mammals, and amphibians/reptiles (herptiles). At the 12th Wildlife Damage Management Conference in Traverse City, Michigan (2005), speakers reviewed issues of introduced birds (Avery and

Tillman 2005), herptiles (Pitt et al. 2005), ungulates (Lowney et al. 2005), carnivores (Witmer et al. 2005), and rodents (Witmer and Eisemann 2005). Pitt and Witmer (2007) reviewed issues associated with invasive predators across several taxa.

In this paper, we compile and update lists of introduced vertebrates (mammals, birds and herptiles) in the US (mainland and Hawaii). We present some of the most problematic species and the types of adverse impacts they cause. We also list the main management methods and tools used to control and eradicate invasive vertebrates in the US. Finally, we discuss some of the remaining challenges in addressing invasive vertebrate management in the US and some research needs. Scientific names are presented in the tables and are not repeated in the text.

VERTEBRATES INTRODUCED IN THE UNITED STATES

We compiled our lists of introduced vertebrate species in the US from a variety of sources, including several publications (e.g., Bury and Luckenbach 1976, Long 1981, Mooney and Drake 1986, Moulton and Pimm 1986, Lever 1987, Hawaii Audubon Society 1989, American Ornithologist's Union 1998, Witmer and Lewis 2001, Long 2003, Teer 2003, Meshaka 2006, Kraus 2007), but also from several state wildlife agency and conservation organization websites (available upon request). Our focus was on the US mainland and Hawaii, so we have not included some of the species introduced to US territories such as the US Virgin Islands, Puerto Rico, and Guam. An important exception is the inclusion of the brown treesnake in Guam as it is a major problem invasive species receiving a considerable investment in research and control efforts. The list we have compiled is quite long because we have included many species that are native to North America, but have been translocated to states or regions in which they did not occur historically. We have also included some species that have expanded their historic range in recent decades because, in many cases, this range expansion has been facilitated, at least in part, by the activities and land uses of humans. The list may actually be considerably longer, but for many species, we cannot yet be sure that they are well established and will sustain themselves over time. For example, Florida agencies use a "10 year rule" of documentation of breeding and establishment in several counties before the species is put on its listed of introduced and established species. It appears that a large portion of the introduced vertebrates occur in Florida, Texas, California, and Hawaii; however, all states have a number of well-established introductions.

At least 81 species of introduced/invasive mammals have become established in parts of the US (Table 1). Mammals were mainly introduced for sport hunting, but also for food and fur (Kraus 2003). The largest single group is ungulates with 33 species. This group includes many species used for sport hunting (e.g., aoudad, gemsbok, nilgai, eland), but also feral populations of species that were used for work (e.g., horses, burros) or for food (e.g., cattle, pigs). The second largest group of mammals is rodents (18), many of which were introduced accidentally via cargo and transport vehicles (commensal rats and mice), but some were purposefully introduced for fur (e.g., nutria). Numerous carnivores (14 species) have been introduced, in some cases for their fur (e.g., foxes, raccoons), but also in efforts to control pests such as rats and snakes (e.g., mongoose, weasels). There are also large populations of feral, formerly companion animals (e.g., dogs, cats) throughout the US Interestingly, at least 6 species of primates have become established in parts of the US

At least 94 species of introduced/invasive birds have become established in the US (Table 2). Most introductions were as pets, but many were introduced for sport hunting (Kraus 2003). Most of these are passerines (39 species), but many are psitticines (22 species, popular animals in the pet industry). There are also a large number (20 species) of "upland game"/galliform birds (both native and non-native) that have been introduced to various parts of the US. Interestingly, many more avian species have been introduced to Hawaii than the mainland (Lever 1987).

At least 86 species of introduced/invasive herptiles have been introduced to the US (Table 3). Most introductions were as pets, but many were also introduced as accidentals in cargo (Kraus 2003). This group of animals is also very popular in the pet industry. Florida is a very large importer of herptiles which may be why that state seems to have the largest number of established species. The largest single group of herptiles is lizards (61 species). Other groups (frogs and toads, turtles, snakes) comprise smaller (6-9 species) and relatively similar numbers of species per group. Only one crocodilian (caiman) has become established in a few parts of the US.

Table 1. Mammals introduced into parts of the US.

MARSUPIALS: Opossum (*Didelphis marsupialis*) Brush-tailed rock wallaby (*Petrogale penicillata*) **PRIMATES:** Squirrel monkey (*Saimiri sciureus*) Vervet monkey (*cercopithecus aethiops*) Crab-eating Monkey (*Macaca fascicularis*) Japanese macaque (*M. fuscata*) Rhesus monkey (*M. mulatto*) Chimpanzee (*Pan troglodytes*) **INSECTIVORES:** Nine-banded armadillo (*Dasypus novemcinctus*) Pallas's mastiff bat (*Molossus molossus*) **LAGOMORPHS:** Eastern cottontail (*Sylvilagus floridanus*) European rabbit (*Oryctolagus cuniculus*) Snowshoe hare (*Lepus americanus*) Black-tailed jackrabbit (*L. californicus*) European hare (*L. europaeus*) White-tailed jackrabbit (*L. townsendii*) **RODENTS:** Arctic ground squirrel (*Spermophilus parryii*) Prairie dog (*Cynomys ludovicianus*) Abert's squirrel (*Sciurus aberti*)	Mexican red-bellied squirrel (*S. aureogaster*) Gray squirrel (*S.* carolin)nsis Fox squirrel (*S. niger*) Red squirrel (*S. vulgaris*) Kangaroo rat (*Dipodomys ordii*) Deer mouse (*Peromyscus maniculatus*) Red-backed vole (*Clethrionomys rutilus*) Muskrat (*Ondatra zibethicus*) Polynesian rat (kiore) (*Rattus exulans*) Norway (brown) rat (*R. norvegicus*) Ship (black, roof) rat (*R. rattus*) Gambian giant pouched rat (*Cricetomys gambianus*) House mouse (*Mus musculus*) Beaver (*Castor canadensis*) Nutria (*Myocastor coypus*) **CARNIVORES:** Red fox (*Vulpes vulpes*) Arctic fox (*Alopex lagopus*) Feral dog (*Canis familiaris*) Coyote (*C. latrans*) Raccoon (*Procyon lotor*) Coatimundi (*Nasua nasua*) White-nosed coati (*N. narica*) Stoat (ermine, short-tailed weasel) (*Mustela erminea*) Least weasel (*M. nivalis*) European polecat (*M. putorius*) American mink (*M. vision)* Small Indian mongoose (*Herpestes auropunctatus*) Feral cat (*Felis catus*) Jaguarundi (*F. yagouaroundi*)	**UNGULATES:** Donkey (burro)(*Equus asinus*) Feral horse (*E. caballus*) Burchell's zebra (*E. burchelli*) Feral pig (*Sus scrofa*) Camel (*Camelus bactrianus*) Axis deer (*Cervus axis*) Fallow deer (*C. dama*) Swamp deer (*C. duvauceli*) Wapiti (American elk, red deer) (*C. elaphus*) Sika deer (*C. Nippon*) Sambar deer (*C. unicolor*) Black-tailed deer (*Odocoileus hemionus*) Roe deer (*Capreolus capreolus*) Moose (*Alces alces*) Reindeer (caribou)(*Rangifer tarandus*) Pronghorn antelope (*Antilocapra Americana*) Eland (*Taurotragus oryx*) Nilgai (*Boselaphus tragocamelus*) Water buffalo (*Bubalus bubalis*) Feral cattle (*Bos Taurus*) Bison (*Bison bison*) Gemsbok (*Oryx gazelle*) Blackbuck (*Antilope cervicapra*) Mountain goat (*Oreamnos americanus*) Chamois (*Rupicapra rupicapra*) Musk-ox (*Ovibos moshatus*) Himalayan tahr (*Hemitragus jemlahicus*) Feral goat (*Capra hircus*) Alpine ibex (*C. ibex*) Aoudad (Barbary sheep) (*Ammotragus lervia*) Mouflon sheep (*Ovis ammon*) Feral sheep (*O. aries*) Bighorn sheep (*O. canadensis*)

Table 2. Birds introduced into parts of the US.

ANSERIFORMES:
Mute swan (*Cygnus olor*)
Mandarin duck (*Aix galericulata*)
Muscovy duck (*Cairina moschata*)
American black duck (*Anas rubripes*)
Mallard (*A. platyrhynchos*)

CICONIIFORMES:
Cattle egret (*Bubulcus ibis*)

GALLIFORMES:
Plain chachalaca (*Ortalis vetula)*
Bobwhite quail (*Colinus virginianus*)
Mountain quail (*Oreortyx picta*)
California quail (*Lophortyx californicus*)
Gambel's quail (*L. gambellii*)
Scaled quail (*Callipepla squamata*)
Chukar partridge (*Alectoris chukar*)
Barbary partridge (*A. Barbara*)
Grey partridge (*Perdix perdix*)
Black francolin (*Francolinus francolinus*)
Grey francolin (*F. pondicerianus*)
Erkel's francolin (*F. erkelii*)
Himalayan snowcock (*Tetragallus himalayensis*)
Common quail (coturnix quail)(*Coturnix coturnix*)
Chinese bamboo partridge (*Bambusicola thoracica*)
Kalij pheasant (*Lophura leucomelana*)
Red jungle fowl (*Gallus gallus*)
Common (ring-necked) pheasant (*Phasianus colchicus*)
Reeve's pheasant (*Syrmaticus reevesii*)
Helmeted guineafowl (*Numida meleagris*)
Common peafowl (*Pavo cristatus*)
White-tailed ptarmigan (*Lagopus leucurus*)
Common turkey (*Melagris gallopavo*)
Chesnut-bellied sandgrouse (*Pterocles exustus*)
Ruffed grouse (*Bonasa umbellus*)

COLUMBIFORMES:
Feral pigeon (rock dove) (*Columba livia*)
African collared dove (*Streptopelia roseogrisea*)
Eurasian collared dove (*S. decaocto*)
Spotted dove (*S. chinensis*)
Barred (zebra) dove (*Geopelia striata*)
White-winged dove (*Zenaida asiatica*)
Mourning dove (*Z. macroura*)

PSITTACIFORMES:
Monk parakeet (*Myiopsitta monachus*)
Ring-necked (rose-winged) parakeet (*Psittacula krameri*)
Canary-winged (white-winged) parakeet (*Brotogeris versicolurus*)
Blue-crowned parakeet (*Aratinga acuticaudata*)
Budgerigar (*Melopsittacus undulatus*)
Green-cheeked Amazon (red-crowned parrot) (*Amazona viridigenalis*)
Yellow-crowned Amazon (*A. ochrocephula*)
Yellow-headed Amazon (*A. oratrix*)
Blue-fronted Amazon (*A. aestiva*)
Lilac-crowned parrot
Senegal parrot (*Poicephalus senegalus*)
Blue-fronted conure (*Aratinga cruentata*)
Brown-throated conure (*A. pertinax)*
Mitered conure (*A. mitrata*)
Nanday conure (black-hooded parakeet) (*Nandayus nenday*)
Lovebird (*Agapornis* spp.)
Cockatiel (*Nymphicus hollandicus*)
Sulphur-crested cockatoo (*Cacatua galerita*)
White-crested cockatoo (*C. alba*)
Giffin's cockatoo (*Cacatua goffini*)

STRIGIFORMES:
Barn owl (*Tyto alba*)

PASSERIFORMES:
Edible-nest swiftlet (*Aerodramus fuciphagus*)
Mariana swiftlet (*A. bartschi*)
Skylark (*Alauda arvensis*)
Western meadowlark (*Sturnella neglecta*)
Red-vented bulbul (*Pycnonotus caferi*)
Red-whiskered bulbul (*P. jocosus*)
Northern mockingbird (*Mimus polyglottos*)
White-rumped shama (*Copsychus malabaricus*)
Melodious laughing thrush (*Garrulax canorus*)
Greater necklaced laughing thrush (*G. pectoralis*)
Red-billed leiothrix (*Leiothrix lutea*)
Japanese bush warbler (*Cettia diphone*)
Varied tit (*Parus varius*)
Japanese white-eye (*Zosterops japonica*)
Saffron finch (*Sicalis flaveola*)
Yellow-faced grassquit (*Tiaris olivacea*)
Red-crested cardinal (*Paroaria coronata*)
Yellow-billed cardinal (*P. capitata*)
Common (northern) cardinal (*Cardinalis cardinalis*)
Spot-breasted oriole (*Icterus pectoralis*)
Yellow-fronted canary (*Serinus mozambicus*)
Common canary (*S. canaria*)
House finch (*Carpodacus mexicanus*)
Red-cheeked condon-bleu (*Uraeginthus benglaus*)
Lavender waxbill (*Estrilda caerulescens*)
Orange-cheeked waxbill (*E. melpoda*)
Common waxbill (*E. astrild*)
Black-rumped waxbill (*E. troglodytes*)
Red avadavat (*Amandava amandava*)
Nutneg manikin (*Lonchura punctulata*)
Black-headed manikin (*L.malacca*)
Warbling silverbill (*L. malabarica*)
Orange bishop (*Euplectes franciscanus*)
Java sparrow (*Padda oryzivora*)
House sparrow (*Passer domesticus*)
European tree sparrow (*P. montanus*)
European starling (*Sturnus vulgaris*)
Common mynah (*Acridotheres tristis*)
Hill mynah (*Gracula religiosa*)
Crested mynah (*Acridotheres cristatellus*)

Table 3. Reptiles and amphibians introduced into parts of the US.

FROGS AND TOADS: Giant toad (cane toad)(*Bufo marinus*) Green-and-black poison dart frog (*Dendrobates auratus*) Greenhouse frog (*Eleutherodactylus planirostris*) Coqui frog (*E. coqui*) Cuban treefrog (*Osteopilus septentrionalis*) Rio Grande leopard frog (*Rana berlandieri*) Green frog (*R. clamitans*) American bullfrog (*R. catesbeiana*) Japanese wrinkled frog (*Glandirana rugosa*) African clawed frog (*Xenopus laevis*) **SALAMANDERS:** Tiger salamander (*Ambystoma tigrinum*) **TURTLES:** Red-eared slider (*Trachemys scripta elegans*) Painted turtle (*Chrysemys picta*) Spiny softshell (*Trionyx spiniferus*) Wattle-necked softshell (*Palea steindachneri*) Chinese softshell (*Pelodiscus sinensis*) Snapping turtle (*Chelydra serpentine*) **CROCODILIANS:** Spectacled (common) caiman (*Caiman crocodilus*) **LIZARDS:** Red-headed agama (*Agama agama*) Giant ameiva (*Ameiva ameiva*) Large-headed anole (*Anolis cybotes*) Green anole (*A. carolinensis*)	Bark anole (*A. distichus*) Hispaniolan green anole (*A. chlorocyanus*) Puerto Rican crested anole (*A. cristatellus*) Knight anole (*A. equestris*) Cuban green anole (*A. porcatus*) Jamaican giant anole (*A. garmani*) Marie Gallant Sail-tailed anole (*A. ferreus*) Brown anole (*A. sagrei*) Brown basilisk (*Basiliscus vittatus*) Veiled chameleon (*Chamaeleo calyptratus*) Jackson's chameleon (*C. jacksonii*) Butterfly lizard (*Leiolepis belliana*) Oriental garden lizard (variable bloodsucker) (*Calotes versicolor*) Rainbow whiptail lizard (*Cnemidophorus lemniscatus*) Giant whiptail lizard (*C.* [*Aspidoselis] motaguae*) New Mexico whiptail lizard (*C. neomexicanus*) Plateau striped whiptail (*C. velox*) Northern curlytail lizard (*Leiocephalus carinatus*) Red-sided curlytail lizard (*L. schreibersii*) Common wall lizard (*Podarcis muralis*) Italian wall lizard (*P. sicula*) Texas horned lizard (*Phrynosoma cornutum*) Black (Gray's) spinytail iguana (*Ctenosaura similis*) Mexican spinytail iguana (*C. pectinata*) Green iguana (*Iguana iguana*) Ashy gecko (*Sphaerodactylus elegans*) Ocellated gecko (*S. argus*) Gold dust day gecko (*Phelsuma laticauda*) Giant day gecko (*P. madagascariensis*) Orange-spotted day gecko (*P. guimbeaui*)	Moorish gecko (*Tarentola mauritanica*) Ringed wall gecko (*T. annularis*) Mourning gecko (*Lepidodactylus lugubris*) Multilating gecko (*Gehyra mutilata*) Rough-tailed gecko (*Cyrtopodion scabrum*) Tokay gecko (*Gekko gecko*) Common house gecko (*Hemidactylus frenatus*) Tropical house gecko (wood stave) (*H. mabouia*) Asian flat-tailed gecko (*H. platyurus*) Indo-Pacific gecko (*H. garnotti*) Mediterranean gecko (*H. turcicus*) Yellow-headed gecko (*Gonatodes albogularis*) Indo-Pacific tree gecko (*Hemiphyllodactylus typus*) Moth skink (*Lipinia noctua*) Azure-tailed skink (*Emoia impar*) Copper-tailed skink (*E. cyanura*) Many-lined grass skink (*Mabuya multifasciata*) Pacific snake-eyed skink (*Cryptoblepharus poecilopleurus*) Plague skink (*Lampropholis delicate*) Western green lacerta (*Lacerta bilineata*) Nile monitor (*Varanus niloticus*) Argentina giant tegu (*Tupinambis merianae*) **SNAKES:** Common boa (*Boa constrictor*) Burmese python (*Python molurus*) Brahminy blind snake (*Ramphotyphlops braminus*) Javan filesnake (*Acrochordus javanicus*) Diamondback water snake (*Nerodia rhombifer*) Brown treesnake (*Boiga irregularis*)

Although we do not address introduced/invasive fish in detail in this paper, it is important to acknowledge the substantial size of this group: at least 150 introduced species (Fuller et al. 1999, Fuller 2003). While some of these were accidental introductions (e.g., from ballast water), most were for sport fishing (e.g., trout [*Oncorhynchus* spp., *Salmo* spp., *Salvelinus* spp.], bass [*Micropterus* spp.]), but many were pet or bait fish releases (Fuller 2003). A few were introduced as a food source (e.g., tilapia [*Tilapia* spp.]) and a few species (e.g., grass carp [*Ctenopharyngodon idella*], mosquito fish [*Gambusia affinis*]) were widely introduced to control aquatic vegetation or mosquito larvae. More details on fish introductions can be found in the reviews by Fuller (2003), Fuller et al. (1999), Pimentel et al. (2005), and Pitt and Witmer (2007).

EXAMPLES OF PROBLEMATIC INTRODUCED VERTEBRATES IN THE UNITED STATES

A number of species within each major taxonomic group of vertebrates pose serious problems over portions of the US. We give a few examples in each group, based on one or more of these criteria: their widespread nature and population sizes, the seriousness of the problems they cause, the amount of investment in prevention and control, and the number of requests of USDA/APHIS Wildlife Services (WS) to deal with specific damage situations. WS involvement in invasive vertebrate damage situations was compiled and discussed by Bergman et al. (2002) and Rennie et al. (2004).

Feral cats are found throughout the US and cause significant predation of native birds and other native animals (Pimentel et al 2005, Witmer et al. 2005, Pitt and Witmer 2007). Feral dogs can be found in most of the states and territories of the US. They pose human safety issues, prey on livestock, and hybridize with some species of native canids (Pimentel et al. 2005, Witmer et al 2005). Feral pigs are found in at least half of the states in the US. They cause serious environmental degradation, prey on native species, damage crops, and pose a disease hazard to livestock and wildlife (Witmer et al. 2003, Pimentel et al. 2005, Pitt and Witmer 2007). Several species of herbivores (exotic and feral rabbits and introduced nutria) also cause ecosystem and crop damage (Witmer and Lewis 2001). One or more species of commensal rats and mice occur everywhere worldwide and in all states and territories of the US. These rodents cause disease and sanitation problems, consumption and contamination of foodstuffs (both in the field and in storage), and property damage (Witmer et al. 1995, Pimentel et al. 2005, Pitt and Witmer 2007). They have also caused the extinction or endangerment of many endemic species on islands (Witmer and Eisemann 2005).

Starlings, pigeons, and house sparrows are found almost worldwide and throughout almost all of the US. They are so well established in the US as to be considered "naturalized" and many people no longer even consider them invasive species. Nonetheless, they cause sanitation and disease problems, compete with native birds, and consume and contaminate livestock feed (Witmer and Lewis 2001, Pimentel et al. 2005). Other serious invasive bird problems are more localized, such as mute swans in several northeastern states. They pose human safety concerns because of their aggressive behavior and they compete with native bird species (Avery and Tillman 2005). Populations of monk parakeets have become established in several states where they cause power outages by nesting in transformers (Avery and Tillman 2005). They also pose a significant threat of crop damage if populations become sizable in agricultural areas. Finally, ring-necked pheasants were introduced to many states for sport hunting. They cause serious crop damage in some localized situations and may compete for resources with native upland bird species (Witmer and Lewis 2001).

Perhaps the most widespread invasive herptile in the US is the bullfrog. While native to the eastern US, bullfrogs have been introduced to many western states. They prey on many aquatic animal species across all taxa, compete for resources, and have contributed to the threatened or endangered status of many regionally-endemic species of frogs (Witmer and Lewis 2001, Pitt et al. 2005, Pitt and Witmer 2007). Other invasive herptile problems in the US are much more localized. In Guam, the brown treesnake predates upon, and competes with, native species of vertebrates and has caused the extinction of several of those species. They also regularly cause power outages and pose a safety hazard to people, especially children (Pimentel et al. 2005, Pitt et al. 2005, Pitt and Witmer 2007). Coqui frogs have become well established in Hawaii where their calling all night disturbs peoples' rest and has caused a decline in property values (Pitt et al. 2005, Pitt and Witmer 2007). Several large, aggressive, carnivorous species of herptiles (in particular, Burmese pythons and Nile

monitor lizards) have become established in parts of Florida. They pose human and companion animal safety hazards, as well as issues of competition and predation with native vertebrate species (Pitt and Witmer 2007).

MANAGEMENT AND ERADICATION OF INTRODUCED/INVASIVE VERTEBRATES

A wide array of methods is used to manage invasive vertebrates in the US and these vary somewhat by taxonomic group (Table 4). Details on most of these methods, how they are used, and their advantages and disadvantages were presented by Conover (2002), Hygnstrom et al. (1994), and VerCauteren et al. (2005). Eradication strategies are more complex and are discussed by taxonomic group.

Management of invasive rodents most often utilizes rodenticides, and primarily anticoagulants (Howald et al. 2007). Traps (kill traps, live traps, glue boards) are used in some situations, but to a much lesser extent. These methods are supplemented in and around buildings, with practices of exclusion, sanitation, and habitat modification (Timm 1994). Day and night shooting is used with some larger species (e.g., nutria; LeBlanc 1994). Most island eradications have utilized anticoagulant rodenticides---hand broadcast, in bait stations, or aerially broadcast (Howald et al. 2007).

A wide array of methods is used for carnivore management and eradication (Nogales et al. 2003, Witmer et al. 2005). Carnivores are captured with live-traps, leg-hold traps, and snares. For smaller species, kill traps (e.g., conibear traps) are also used. Shooting (day, night, with calling) is often used. Occasionally, aerial shooting is used. Exclusion is sometimes used, especially to protect small colonies of endangered species. Toxicants are used on a limited basis: toxic baits and the M-44 cyanide device are sometimes used, especially on islands (Nogales et al. 2003, Witmer et al. 2005). A number of methods are not effective with carnivores and rodents (frightening devices, repellents, taste aversion), although research continues on these and other methods. Few carnivore eradications have been attempted in the US. However, introduced foxes have been eradicated from several Aleutian Islands with the use of shooting, traps, and toxic baits (Ebbert 2000).

A wide array of methods is used for ungulate management and eradication (Butchko et al. 2003, Campbell and Donlan 2005, Lowney et al. 2005). These include shooting (day, night, over bait, aerial), trapping (individual cage traps, snares, group/corral cage traps), pursuit with dogs, exclusion, food removal, and Judas animals. Eradications have occurred on a few small islands and on some sizable, fenced/contained areas of the mainland (Butchko et al. 2003, Campbell and Donlan 2005, Lowney et al. 2005). Generally, several methods have been employed to assure success.

Table 4. Methods[a] used to manage and eradicate invasive vertebrate species in the US.

Method: / **Group:**	**Trap**	**Shoot**	**Toxi-cants**	**Dogs**	**Judas animals**	**Introduced predator**	**Habitat Manip.**	**Barriers**	**Other methods**
Rodents	X	N/O	X	N/O		X	X	X	B
Ungulates	X	X		X	X		X	X	F
Carnivores	X	X	X	X		X		X	B, C, T
Birds	X	X	X	X			X	X	F, D
Herptiles	X		X	X				X	

[a]N/O = nutria only, B = bounty, F = frightening devices, C = compensation, T = trap/neuter/release, D = egg/nest destruction

Methods used to manage invasive bird populations are similar to those used for mammals: traps (with or without live bird decoys), shooting, exclusion, and limited use of toxicants (DRC 1339; Witmer and Lewis 2001, Millet et al. 2004, Avery and Tillman 2005, Pitt and Witmer 2007). The exceptions are that egg and nest destruction is sometimes used with birds and frightening devices are often used to protect relatively small areas. While few, if any, bird eradications have been conducted in the US, Millett et al. (2004) used shooting and toxicants to eradicate invasive common mynahs from several small islands in the Seychelles. They noted that larger islands were much more difficult, if not impossible, to eradicate, and that re-invasion was often a problem on all but the most remote islands.

Our tool box for management and eradication of invasive vertebrates is perhaps weakest for amphibians and reptiles (Witmer and Lewis 2001, Pitt and Witmer 2007). Most methods development has occurred for brown treesnakes in Guam and coqui frogs in Hawaii (Pimentel et al. 2005, Pitt et al. 2005, Pitt and Witmer 2007). Trapping, hand-capture or pit fall traps are perhaps most commonly used with herptiles. Drift fences are often used to increase effectiveness by directing animals to traps or pit falls. Night search-and-capture with spotlights can be used, and with brown treesnakes, night fence searches are conducted. Detector dogs are used to inspect cargo for brown treesnakes and to help locate Burmese pythons in Florida's Everglades National Park. Toxicants have been developed and registered for brown treesnakes (acetaminophen) and for coqui frogs (citric acid and hydrated lime solutions; Pitt et al. 2005, Pitt and Witmer 2007). We are not aware of any eradications of introduced herptiles in the US.

MAJOR ISSUES IN DEALING WITH INVASIVE VERTEBRATES IN THE UNITED STATES

While some progress has been, and is being, made with invasive vertebrates in the US, there are still many challenges and issues to resolve (National Invasive Species Council 2001, Pimentel et al. 2005). The major emphasis, in terms of attention and funding, for invasive species in the US has been focused on plants, insects, and pathogens (Pimentel et al. 2005). Relatively little effort and few resources have been directed to vertebrates with the main exceptions of brown treesnakes in Guam and feral pigs (in many states).

Public perception and lack of support have affected efforts to manage or eradicate vertebrate species in the US, as elsewhere in the world (National Invasive Species Council 2001). Knowledge levels regarding invasive species and the harm they can cause are relatively low amongst the general public (National Invasive Species Council 2001, Conover 2002). Furthermore, the public does not readily distinguish between native and non-native species: as long as an animal looks nice and is not threatening people or causing undue harm, the public tends to view species equally (Wittenberg and Cock 2001). Once it has been established that a species will not cause undo environmental or human resource harm, it can be placed on a "white" list (Fowler et al. 2007). By and large, in the US, species importations are viewed as "innocent until proven guilty" ("gray" list) and what is needed is the development of a much more inclusive prohibited species "black" list (Witmer and Lewis 2001, Fowler et al. 2007, Pitt and Witmer 2007). The ultimate solution to an invasive species is the eradication of all individuals in a given area; however, much of the public has a strong dislike for the killing of animals (Conover 2002). Certain species such as feral cats, feral dogs, wild horses, and primates are particularly sensitive species to address. Furthermore, much of the public has a strong fear and distrust of chemicals, and in particular, toxicants. Hence, the management of invasive vertebrates, like all wildlife, is being conducted in an increasingly complex arena (Conover 2002, Fall and Jackson 2002).

The pet industry is a well organized, large, and influential industry in the US (Ginsburg 2004). Exotic pets are very popular with a sizable portion of the public. And yet, the pet industry is a major pathway for the introduction of vertebrates into the US (Kraus 2003). Very few vertebrate species are prohibited from entry into the US with a prevailing attitude of "innocent until proven guilty" (Witmer and Lewis 2001, Pitt and Witmer 2007). Greater cooperation, enforcement, and regulation of the pet industry is needed.

Access to all relevant land and properties is essential for the successful management and eradication of invasive vertebrates. However, mangers often face the situation where the work is needed across a wide array of jurisdictions and ownerships. Getting permission to access all these

areas rarely occurs and can prevent the success of even a well-planned, well-funded eradication effort. Furthermore, land management mandates and regulations of federal and state agencies vary considerably. This affects the type of management activities (burning, chemical use), type of vehicles, and tools (leg-hold traps, firearms, toxicants) that can be used on certain properties. Some laws actually protect invasive vertebrate species, such as the Wild Horse and Burro Act and the Migratory Bird Treaty Act. The latter was recently amended to exclude some non-native bird species in the US such as the mute swan.

Finally, there is an overall lack of coordination and cooperation across jurisdictions and agencies of all levels of government in the US. One of the goals of the National Invasive Species Management Plan (National Invasive Species Council 2001) is to rectify that situation. Eradicating an invasive vertebrate species is rarely an easy undertaking. Very careful planning is needed, along with adequate resources, public and agency buy-in, highly trained and motivated personnel, contingency plans, and a sustained effort (Broome 2005). Each situation is unique in one or more ways; hence, a cook-book approach cannot be used (Broome 2005).

With the possible exception of rodents and ungulates, the methods and strategies used for management, and especially eradication, of invasive vertebrates need improvement (Wittenberg and Cock 2001). Much research needs to be conducted to improve detection methods. Attractants are needed to attract individuals to traps, bait stations, and detection stations. Method improvements are needed to ensure effective and safe delivery of toxicants, vaccines, and fertility control agents. Trained, rapid response teams are needed for many more invasive species. Accessible databases on potential invasive species are needed to summarize species identification, biology, ecology, and effective detection and management methods. The databases should also identify expertise and literature that can be consulted. Although a variety of databases and websites exist (Sellers et al. 2005), it would be very useful if these could be centralized and standardized (Sellers et al. 2004). Finally, risk assessments are needed to determine on which species we should focus our efforts and resources (Hayes 2003).

CONCLUSION

At least 161 species of introduced/invasive vertebrates occur in the US. We suspect that invasive vertebrate species will continue to challenge land and resource managers, ecologists, and biologists for a long time to come. We also suspect that the list of invasive vertebrate species in the US will continue to grow; but, hopefully, some species will also be removed from the list. We have had some good successes with invasive species management and eradications, especially on islands, but also on some areas of the mainland. As a result of this, along with our collaborations with international colleagues and a growing interest and involvement by the public and agencies, we are becoming more knowledgeable and pro-active in responding to invasive vertebrate species. We still have a long way to go in terms of national organization and cooperation on these issues, resolving various logistical and financial issues, and improving methods and strategies for many more species.

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