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ENVIRONMENTAL AND ECONOMIC COSTS OF VERTEBRATE SPECIES INVASIONS INTO THE UNITED STATES

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Abstract: The more than 50,000 species of plants, animals, and microbes introduced into the United States (US) cause more extinction of native species than most any other threat and cause more than \$120 billion in damages and control costs each year. In particular, invasive mammals and birds cause major environmental and economic losses totaling about \$46 billion per year in damage and control costs per year. Feral cats, rats, and hogs are especially serious pests. Pigeons and starlings are a major concern in cities and US agriculture. Prevention and management strategies will be discussed.

Key Words: alien species, control costs, economics, environment, invasive species, management strategies, pests, vertebrates.

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INTRODUCTION

Of the estimated 750,000 species of organisms in the United States (US), an estimated 50,000 species of plants, animals, and microbes have been introduced into the nation (Pimentel et al. 2000). Most of the vertebrate and plant species that are invaders were intentionally introduced, whereas most of the microbes and invertebrates that have invaded the US were accidentally introduced.

The total damage and control costs from all invading species in the US are estimated to be about \$120 billion per year (Pimentel 2005). Most of the benefits come from the 99% of crops and livestock that were intentionally introduced (USCB 2007). The benefit from the agricultural system alone is estimated to be about \$800 billion per year (USCB 2007).

The focus of this article will be on vertebrate species that were introduced into the US (Table 1). As mentioned, most of these species were intentionally introduced.

MAMMALS

About 28 species of mammals have been introduced into the US; these include dogs (*Canis familiaris*), cats (*Felis catus*), horses (*Equus caballus*), burros (*E. asinus*), cattle (*Bos Taurus*), sheep (*Ovis aries*), pigs (*Sus scrofa*), goats (*Capra hirus*), and deer (*Cervus spp.*) (Drost and Fellers 1995, Layne 1997). Several of these species have escaped or were released into the wild; some have become pests by preying on native animals, grazing on vegetation, or intensifying soil erosion. For

example, goats introduced on San Clemente Island, California, are responsible for the extinction of 8 endemic plant species as well as the endangerment of 8 other native plant species (Kurdila 1995).

Many small mammals have also been introduced into the US. These species include a number of rodents, (black or ship rat [*Rattus rattus*], Norway or brown rat [*Rattus norvegicus*], house mouse [*Mus musculus*], and European rabbit [*Oryctolagus cuniculus*], Layne 1997).

Some introduced rodents have become serious pests on farms, in industries, and in homes (Layne 1997). Rats and mice are particularly abundant and destructive on farms. On poultry farms, there is approximately 1 rat per 5 chickens (D. Pimentel, unpublished data, Smith 1984). Using this ratio, the total rat population on US poultry farms may easily number more than 1.8 billion (USDA 2006). Assuming that the number of rats per chicken has declined because of improved rat control since these observations were made, I estimate that the number of rats on poultry and other farms is approximately 1.5 billion. With an estimated additional 1 rat per person in homes and related areas (Wachtel and McNeely 1985, Discover 2006), there are an estimated 300 million introduced rats in the US (USCB 2007).

If we assume, conservatively, that each adult rat consumes or destroys stored grains (Chopra 1992, Ahmed et al. 1995) and other materials valued at \$15/yr, then the total cost of destruction by introduced rats in the US is more than \$27 billion per year. In addition, rats cause fires by gnawing

Table 1. Vertebrate animal introductions into the US and the total estimated damage and control costs caused by these animals.

Category	Species	Damage and Control Costs (x \$1 million)
Mammals	Wild horses and burros	\$5
	Feral pigs	\$1,500
	Mongoose	\$50
	Rats	\$27,000
	Cats	\$14,000
	Dogs	\$620
Birds	Pigeons	\$1,400
	Starlings	\$800
Reptiles & amphibians	Brown treesnakes	\$5.6
Fish		<u>\$1,000</u>
Total		\$46,380.6

electric wires, pollute foodstuffs, and act as vectors of several diseases, including salmonellosis and leptospirosis, and, to a lesser degree, plague and murine typhus (Richards 1989). They also prey on some native invertebrate and vertebrate species like birds and bird eggs (Amarasekare 1993, Woodworth and Fancy 2006).

One of the first cases of the failure of biological control is the use of the Indian mongoose (*Herpestes auropunctatus*). It was first introduced into Jamaica in 1872 for biological control of rats in sugarcane (Pimentel 1955). It was subsequently introduced to the territory of Puerto Rico, other West Indian Islands, and Hawaii for the same purpose. In some cases, the mongoose controlled the black rat, but not the Norway rat, and it preyed heavily on native ground nesting birds (Pimentel 1955, Vilella and Zwank 1993). It also preyed on beneficial native amphibians and reptiles, causing at least 7 amphibian and reptile extinctions in Puerto Rico and other islands of the West Indies (Henderson 1992). In addition, the mongoose emerged as the major vector and reservoir of rabies and leptospirosis in Puerto Rico and other islands (Everard and Everard 1992). Based on public health damages, killing of poultry in Puerto Rico and Hawaii, extinctions of amphibians and reptiles, and destruction of native birds, it is estimated that the mongoose is causing approximately \$50 million in damages each year in Puerto Rico and the Hawaiian Islands (Pimentel et al. 2000).

Introduced cats have also become a serious threat to some native birds and other animals in the US. There are an estimated 67 million pet cats in the US (USCB 2007), plus as many as 30 million feral

cats (Luoma 1997). Cats prey on native birds (Fitzgerald 1990), plus small native mammals, amphibians, and reptiles (Dunn and Tessaglia 1994). Estimates are that feral cats in Wisconsin and Virginia kill more than 3 million birds in each state per year (Luoma 1997). Based on the Wisconsin and Virginia data, I assume that 5 birds are killed per feral cat/year; McKay (1996) reports that pet cats kill a similar number of birds as feral cats. Thus, about 470 million birds are killed by cats per year in the nation. Each adult bird can be valued at \$30. This cost per bird is based on the literature that reports that a bird watcher spends \$0.40 per bird observed, a hunter spends \$216 per bird shot, and specialists spend \$800 per bird reared for release; in addition, note that EPA fines polluters \$10 per fish killed, including small, immature fish (Pimentel and Greiner 1997). Therefore, the total damage to US bird population is approximately \$14 billion/yr. This figure does not include small mammals, amphibians, and reptiles that are killed by feral and pet cats (Dunn and Tessaglia 1994).

Like cats, most dogs introduced into the US were introduced for domestic purposes, but some have escaped into the wild. Many of these wild dogs run in packs and kill deer, rabbits, and domestic cattle, sheep, and goats. Carter (1990) reported that feral dog packs in Texas cause more than \$5 million in livestock losses each year. Dog packs have also become a serious problem in Florida (Layne 1997). In addition to the damages caused by dogs in Texas, and conservatively assuming \$5 million for all damages for the other 49 states combined, total losses in livestock kills by

dogs per year would be approximately \$10 million per year.

Moreover, approximately 4.7 million people are bitten by feral and pet dogs annually, with 800,000 cases requiring medical treatment (Sacks et al. 1996). Centers for Disease Control estimates medical treatment for dog bites costs \$165 million/yr, and the indirect costs, such as lost work, increase the total costs of dog bites to \$250 million/yr (Colburn 1999, Quinlan and Sacks 1999). In addition, dog attacks cause between 11 and 14 deaths per year, and 80% of the victims are small children (CDC 1997). The total damage and control costs associated with dogs are estimated to be \$620 million (Pimentel et al. 2005).

Horses and burros, deliberately released in the western US, have attained wild populations of approximately 50,000 animals (Pogacnik 1995). These animals graze heavily on native vegetation, allowing non-indigenous annuals to displace native perennials (Rosentreter 1994). Burros inhabiting the northwestern US also diminish the primary food sources of native bighorn sheep and seed-eating birds, thereby reducing the abundance of these native animals (Kurdila 1995). In general, the large populations of introduced wild horses and burros cost the nation an estimated \$5 million/yr in forage losses (Pimentel et al. 2000).

Feral pigs, native to Eurasia and North Africa, have been introduced into some US parks for hunting, including parks in the California coastal prairie and Hawaiian Islands, where they have substantially changed the vegetation in these parks (Kotanen 1995). In Hawaii, more than 80% of the soil is bare in regions inhabited by pigs (Kurdila 1995). This disturbance allows annual plants to invade the overturned soil and intensifies soil erosion. Pig control per park in Hawaii (approximately 1,500 pigs/park) (Stone et al. 1992) costs about \$150,000/yr. Assuming that the 3 parks in Hawaii have similar pig control problems, the total is \$450,000/yr (R. Zuniga, Cornell University, personal communication).

Feral pigs have also become a serious problem in Florida and Texas where their populations have risen to about 2 million in each state (Giuliano and Tanner 2007, Mapston 2007). Another 1 million hogs are estimated to be in Hawaii, California, and other southern US. On the Edwards Plateau and Rolling Plains region the damages to agriculture average greater than \$10,000 per landowner (Texas Association of Counties 2003). In other areas of Texas, the damage ranges between \$1,800 and \$6,000. In addition, landowners spend an average

of \$2,631 for control and/or repairs (Texas Association of Counties 2003).

In Texas, and elsewhere, pigs damage grain, peanut, soybean, cotton, hay, and various vegetable crops, and the environment (Rollins 1998). Pigs also transmit and are reservoirs for 30 viral and bacterial diseases of livestock and human diseases, including brucellosis, pseudobrucellosis, and trichinosis (Davis 1998, Williams and Barker 2001).

Nationwide, as mentioned, there are an estimated 5 million feral pigs. Based on crop damages and control costs of about \$300 per pig annually, feral pigs in the US are causing at least \$1.5 billion in damages and control costs.

BIRDS

Approximately 100 of the 1,000 bird species in the US are exotic (Temple 1992, EPA 2005). Of the approximately 100 introduced bird species, only 5%, including chickens, are considered beneficial. Most (56%), though, are considered pests (Temple 1992). Pest species include the common pigeon (*Columba livia*), which was introduced into the US for agricultural purposes.

Introduced bird species are an especially severe problem in Hawaii. A total of 54 of the 142 non-indigenous bird species introduced since 1850 in Hawaii are still extant on the islands (Moulton and Pimm 1983, Pimm 1991, Earlham College 2002). One such species, the common myna (*Acridotheres tristis*), was introduced to help control pest cutworms and armyworms in sugarcane (Kurdila 1995). However, it became the major disperser of seeds of an introduced pest weed, *Lantana camara*. In the continental US, the English house sparrow (*Passer domesticus*) was introduced in 1853 to control the canker worm (Laycock 1966, Roots 1976). By 1900, they had become pests because they damage plants around homes and public buildings and consume wheat, corn, and the buds of fruit trees (Laycock 1966). Furthermore, English sparrows harass native birds, including robins (*Turdus migratorius*), Baltimore orioles (*Icterus galbula*), yellow-billed cuckoos (*Coccyzus americanus*), and black-billed cuckoos (*C. erythrophthalmus*), and displace native bluebirds (*Sialia* spp.), nuthatches (*Sitta* spp.), black-capped chickadees (*Parus* spp.), house wrens (*Troglodytes aedon*), tree swallows (*Iridoprocne bicolor*), tufted titmice (*Parus bicolor*), purple martins (*Progne subis*), and cliff swallows (*Petrochelidon pyrrhonota*) from their nesting sites (Laycock 1966,

Roots 1976, Long 1981, Purple Martin Society 2007). They are also associated with the spread of about 29 human and livestock diseases (Weber 1979).

The single-most serious pest bird in the US is the exotic common pigeon that exists in most cities of the world, including those in the US (Robbins 1995). Pigeons are considered a nuisance because they foul buildings, statues, cars, and sometimes people, and feed on grain (Long 1981, Smith 1992). The control costs of pigeons are at least \$9 per pigeon per year (Haag-Wackernagel 1995). Assuming 1 pigeon per ha in urban areas (Johnston and Janiga 1995) or approximately 0.5 pigeons per person, and using potential control costs as a surrogate for losses, pigeons cause an estimated \$2 billion/yr in damages. These control costs do not include the environmental damages associated with pigeons, which serve as reservoirs and vectors for over 50 human and livestock diseases, including parrot fever, ornithosis, histoplasmosis, and encephalitis (Weber 1979, Long 1981).

Some birds threaten crop production. European starlings (*Sturnus vulgaris*) are serious pests and are estimated to occur at densities of more than 1 per ha in agricultural regions (Moore 1980). Starlings are capable of destroying as much as \$2,000 worth of cherries per hectare (Feare 1980). In grain fields, starlings consume about \$6/ha of grain (Feare 1980). Conservatively assuming \$5/ha for all damages to several crops in the US, the total loss due to starlings would be approximately \$800 million/yr. In addition, these aggressive birds have displaced numerous native birds (Laycock 1966). Starlings have also been implicated in the transmission of 25 diseases, including parrot fever and other diseases of humans (Laycock 1966, Weber 1979).

AMPHIBIANS AND REPTILES

Amphibians and reptiles introduced into the US number about 53 species. All these non-indigenous species occur in relatively warm states. Florida is now host to 30 species and Hawaii to 12 (McCoid and Kleberg 1995, Lafferty and Page 1997). The negative ecological impacts of several of these exotic species have been enormous.

The brown treesnake (*Boiga irregularis*) was accidentally introduced to the snake-free US territory of Guam immediately after World War II, when military equipment was moved onto Guam (Fritts and Rodda 1995). Soon the snake population reached densities of 100 per ha, and dramatically

reduced native bird, mammal, and lizard populations. Of the 13 species of native forest birds originally found on Guam, only 3 still exist (Rodda et al. 1997); of the 12 native species of lizards, only 3 have survived (Rodda et al. 1997). The snake eats chickens, eggs, and caged birds, causing major problems to small farmers and pet owners. It also crawls up trees and utility poles and has caused power outages on the island. One island-wide power outage caused by the snake cost the power utility more than \$250,000 (Teodosio 1987). Local outages that affect businesses are estimated to cost from \$2,000 to \$10,000 per commercial customer per year (Coulehan 1987). With about 86 outages per year (BTSCP 1996), my estimate of the cost of snake-related power outages is conservatively \$1 million/yr.

In addition, the brown treesnake is slightly venomous, and has caused public health problems, especially when it has bitten children. At one hospital emergency room, about 26 people per year are treated for snake bites (OTA 1993). Some bitten infants require hospitalization and intensive care, at an estimated total cost of \$25,000 per year.

The total costs of endangered species recovery efforts, environmental planning related to snake containment on Guam, and other programs directly stemming from the snake's invasion of Guam reach more than \$1 million per year; in addition, up to \$2 million per year is invested in research to control this serious pest. The brown treesnake has also invaded Hawaii but thus far has been exterminated. Hawaii's concern about the snake, though, has prompted the federal government to invest \$1.6 million per year in brown treesnake control (Holt 1997-1998). The total cost associated with the snake is therefore more than \$5.6 million/yr.

FISH

A total of at least 152 non-indigenous fish species has been introduced into the US (Courtenay 1993, 1997, Fuller et al. 2005). Most of these introduced fish have been established in states with mild climates, such as Florida (50 species) (Courtenay 1997) and California (56 species) (Dill and Cordone 1997). In Hawaii, 33 non-indigenous freshwater fish species have become established (Maciolek 1984). Forty-four native species of fish are threatened or endangered in the US by non-indigenous fish species (Wilcove and Bean 1994). An additional 27 native fish species are also negatively affected by introductions (Wilcove and Bean 1994, Fuller et al. 2005).

Introduced fish species frequently alter the ecology of aquatic ecosystems. For instance, the grass carp (*Ctenopharyngodon idella*) reduces natural aquatic vegetation, while the common carp (*Cyprinus carpio*) reduces water quality by increasing turbidity. These changes have caused the extinctions of some native fish species (Taylor et al. 1984).

Although some native fish species are reduced in numbers, are driven to extinction, or hybridized by non-indigenous fish species, alien fish do provide some economic benefits in the improvement of sport fishing. Sport fishing contributes \$69 billion to the economy of the US (Bjergo et al. 1995, Pimentel 2005, USCB 2007). However, even taking into account these economic benefits, based on the more than 40 non-indigenous species that have negatively affected native fishes and other aquatic biota, a conservative estimate puts the economic losses due to exotic fish at more than \$1 billion annually. The benefit of the Great Lakes Fishery alone is estimated to be \$4.5 billion per year (Pimentel 2005).

CONCLUSION

With more than 50,000 introduced species of plants, animals, and microbes in the US, only a portion of these cause significant damage to agriculture, forestry, and natural ecosystems, and require costly control measures. Vertebrates are one group of invasive species that cause significant ecological and environmental damages. My best estimate for the annual cost of vertebrate species in the US is approximately \$46 billion.

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