chapter seventeen

*Economic and environmental threats of alien plant, animal, and microbe invasions**

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17.1 Introduction

Quantifying the environmental damage and loss of biodiversity due to alien species invasions worldwide is complicated by the fact that only some 1.5 million of the estimated 10 million species on earth have been identified and described.[1] The total numbers of introduced species in the United States, the United Kingdom, Australia, South Africa, India, and Brazil range from about 2000 to 50,000 species (Table.17.1). Many native species are threatened by competition and predation from invaders, while many other species are endangered by hybridization with alien species or major ecosystem changes caused by these species. Nonetheless, a total of more than 120,000 species of plants, animals, and microbes are known to have invaded these six nations; these alien species provide a base to assess several environmental threats such invaders pose (Table 17.1).

Given the number of species that have invaded the six nations studied here, we estimated that 480,000 alien species have been introduced into the varied ecosystems on earth. Many such introduced species, such as corn, wheat, rice, plantation forests, domestic chicken, cattle, and others, are beneficial and now provide more than 98% of the world's food supply — a value of more than $5 trillion per year.[2]

All crop and livestock species originated somewhere; the chicken, for example, is from Southeast Asia. Other alien species are used for landscape restoration, biological pest control, sport, pets, and food processing. However, alien species are also known to cause major economic losses in agriculture, forestry, and several other segments of the world economy; they also compromise ecological integrity.[3,4]

In the recent past, the rates and risks associated with alien species introductions have increased enormously, because human population growth and human activities that alter the environment have escalated rapidly.[4] Currently, there are 6 billion humans on earth.[5] Large numbers of people are traveling faster and farther, and more goods and materials are being traded among nations.[2,6] These human activities are accelerating the spread of alien species of plants, animals, and microbes worldwide.

This study assesses the magnitude of some of the environmental and economic impacts caused by alien plant, animal, and microbe invasions in the United States, the United Kingdom, Australia, South Africa, India, and Brazil. Although these nations have some of the best national data in the world, the total number of invading species is still unknown, making the assessment incomplete and extremely difficult. The lack of some data means that our economic and environmental information is underestimated.

17.2 Methodology

The approach employed in this investigation was to assemble all the published data on available invasive species in the countries under review. The number of alien species for each major group was totaled; these data are found in Table 17.1. Published information on the environmental impacts of non-indigenous species was also assembled. In addition, published data were assembled on the economic impacts of invasive species on crops, pastures, forests, public and livestock health, and natural ecosystems. In the cases where the data were available, control-cost data were tabulated and included with the economic cost data in Tables 17.2, 17.3, and 17.4.

17.3 Alien species in the United States, the United Kingdom, Australia, South Africa, India, and Brazil

Alien species cause major environmental and economic problems worldwide. In the United States, about 400 of the 958 species on the U.S. Threatened or Endangered Species

Table 17.1 Species Number per Category in the United States, United Kingdom, Australia, South Africa, India, and Brazil

	United States		United Kingdom		Australia		South Africa		India		Brazil	
Category	Total spp. number	Number Alien spp.	Total spp. number	Number Alien spp.	Total spp. number	Number Alien spp.	Total spp. number	Number Alien spp.	Total spp. number	Number Alien spp.	Total spp. number	Number Alien spp.
Plants	42,000[a]	25,000[a]	27,515[f]	26,000f	20,000l	1,952[m]	24,000[q]	8,750[r]	45,000[y]	18,000[z]	55,000[p]	11,605[ii]
Mammals	346[b]	20[c]	54[g]	17[g]	296[l]	20[l]	247[p]	16[s]	316[p]	30[aa]	428[jj]	25[kk]
Birds, reptiles, and amphibians	650[b]	97[a]	542[h]	47[h]	850[n]	70[n]	725[t]	8[t]	1,221[bb]	4[cc]	1,635[ii]	3[ll]
	247[b]	53[a]	80[i]	48[i]	700[o]	20[o]	394[u]	24[u]	741[dd]	NA	985[mm]	NA
Fishes (Freshwater)	938[e]	138[a]	54[j]	12[j]	216[o,p]	29[o,p]	220[v]	20[w]	2,546[ee]	300[ff]	3,000[mm]	76[ii]
Arthropods	650,000[e]	4,500[a]	24,700[k]	1,000[k]	85,920[li]	150[li]	86,000[w,x]	NA	54,430[gg]	1,100[hh]	1,000,000[nn]	NA
Microbes	134,644[d]	20,000[e]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

a= 4, b=69, c=74, d=148-153, e=estimate, f=67, g=154,155, h=88, i=156, j=158, k=39, l=34, m=21, n=89,159, o=99, p=69, q=160, r=161, s=123, t=162, u=101, v=163, w=82, x=122, y=164, aa=170, bb=173, cc=174, dd=175, ee=175, ff=176, gg=177, hh=178, ii=70, jj=165, kk=166, ll=167, mm=168, nn=169.

Table 17.2 Economic Losses to Introduced Pests in Crops, Pastures, and Forests in the United States, United Kingdom, Australia, South Africa, India, and Brazil (billion dollars per year)

Introduced pest	United States	United Kingdom	Australia	South Africa	India	Brazil	Total
Weeds							
Crops	27.9	1.4	1.8	1.5	37.8	17.0[d]	87.4
Pastures	6.0	—	0.6	—	0.92	—	7.52
Vertebrates							
Crops	1.0[a]	1.2[b]	0.2[c]	—	—	—	2.4
Arthropods							
Crops	15.9	0.96	0.94	1.0	16.8	8.5	44.1
Forests	2.1	—	—	—	—	—	2.1
Plant pathogens							
Crops	23.5	2.0	2.7	1.8	35.5	17.1	82.6
Forests	2.1	—	—	—	—	—	2.1
Total	**78.5**	**5.56**	**3.24**	**4.3**	**91.02**	**42.6**	**228.72**

a = Losses due to English starlings and English sparrows[4]

b = Calculated damage losses from the European rabbit (see text)

c = 34

d = Pasture losses included in crop losses

— = data not available

List are considered at risk primarily because of competition with and predation by non-indigenous species.[7] In the fynbos region of South Africa, 80% of the threatened species are endangered because of invading alien species.[8] Most plant and vertebrate animal introductions have been intentional, whereas most invertebrate and microbe introductions have been accidental.[9] More than 120,000 species of plants, animals, and microbes have invaded the six nations investigated here, and many of these species are causing a wide array of damage both to managed and natural ecosystems (Table 17.1). Based on data available, the percentage of the total invading species for each nation is United Kingdom 53%, India 19%, South Africa 7%, United States 6%, Australia 3%, and Brazil 1% (Table 17.1).

17.4 Crop, pasture, and forest losses

Introduced plant, animal, and microbe species cause $55 billion to $248 billion per year in losses to world agriculture.[10]

17.4.1 Weeds

In crop systems, including forage crops, many intentionally introduced plant species have become weed pests.[11] Most weeds are accidentally introduced with crop seeds, from ship-ballast soil, or from various imported plant materials.[4]

In U.S. agriculture, weeds cause a reduction of 12% in potential crop yields. In economic terms, this reduction represents about a $33 billion loss in crop production annually, based on the crop potential value of all U.S. crops of more than $267 billion per year.[2] Based on the estimate that about 73% of the weeds are non-indigenous,[12] it is likely that about $27.9 billion of these crop losses are due to introduced weeds (Table 17.2).

In U.S. pastures, 45% of weeds are alien species.[12] U.S. pastures provide about $10 billion in forage crops annually,[13] and the estimated loss due to weeds is $2 billion.[14] Since

Table 17.3 Environmental Losses to Introduced Pests in the United States, United Kingdom, Australia, South Africa, India, and Brazil (billion dollars per year)

Introduced Pest	United States	United Kingdom	Australia	South Africa	India	Brazil	Total
Plants	0.148[a]	—	—	0.095[j]	—	—	0.178
Mammals							
Rats	19.000[b]	4.100[k]	1.200[k]	2.700[l]	25.000[l]	4.00[l]	56.400
Other	18.106[c]	1.200[m]	4.655[n]	—	—	—	23.961
Birds	1.100[d]	0.270[o]	—	—	—	—	1.370
Reptiles & Amph.	0.006[e]	—	—	—	—	—	0.006
Fishes	1.000[f]	—	—	—	—	—	1.000
Arthropods	2.137[g]	—	0.228[p]	—	—	—	2.365
Mollusks	1.305[h]	—	—	—	—	—	1.305
Livestock diseases	9.000[i]	—	0.249[i]	0.100[i]	—	—	9.349
Human Diseases	6.500[i]	1.000[i]	0.534[j]	0.118[i]	—	2.33[j]	10.467
Total	**58.299**	**6.570**	**6.866**	**3.013**	**25.000**	**6.733**	**106.481**

a = A total of $45 million/yr in purple loosestrife control plus $100 million/yr in aquatic weed control[4]

b = 4

c = Damages from cats at $17 billion/yr, pigs $800.5 million/yr, dogs $250 million/yr, mongooses $50 million/yr, and horses and burros $5 million/yr[4]

d = Damages from pigeons[4]

e = Damages from the brown tree snake[4]

f = Damages from invading fish species[4]

g = Damages from the imported fire ant estimated to be $1 billion/yr, gypsy moth $11 million/yr, varroa mite $82 million/yr, Formosan termite $1 billion/yr, and green crab $44 million/yr[4]

h = Control/damage costs from the zebra mussel, Asian clam, and shipworm[4]

i = See text

j = About $40 million/yr for aquatic weed control; $50 million/yr for Working for Water; and $5 million/yr preventing plant invasions

k = Estimated 4.6 rats per capita and $15 damages /rat/yr[4]

l = Estimated 2.7 rats per capita in India (similar estimates for South Africa and Brazil)[75] and $10 damages/rat/yr[4]

m = Estimated 1 cat/3 people and 1/3rd are feral and each feral cat kills 2 birds/yr, then damages are calculated to be $1.2 billion/yr[4]

n = Estimated 18 million feral cats in Australia[82] and these cats kill 144 million birds/yr, then damages are calculated to be $4.3 billion/yr.[4] In addition, feral pigs are causing $80 million/yr in damages[34] and mice approximately $75 million/yr[179]

o = Estimated 0.5 pigeons/person and damages calculated to be $9/pigeon/yr, then damages are approximately $270 million/yr[4]

p = Three exotic insect and mite species cause $228 million/yr in damages to the wool industry[133]

— = data not available

about 45% of the weeds are alien,[12] the approximate forage losses due to non-indigenous weeds are nearly $1 billion a year. According to former Interior Secretary Bruce Babbitt,[15] ranchers spend about $5 billion a year to control invasive alien weeds in pastures and rangelands, but these weeds continue to spread (Table 17.2).

Most of the United Kingdom's alien plants occur in few habitats. More than 80% of alien species are present in waste ground areas, urban sites, roadsides, and similar disturbed habitats.[16] An estimated 63% of the alien plant species grow in hedges and scrub areas.[17] Vegetation in rock walls and woodlands consists of about 40% alien species.

Table 17.4 The Number of Humans with AIDS or HIV Infections and Health Care Costs (x 1 million) in the United States, United Kingdom, Australia, South Africa, India, and Brazil

	United States	United Kingdom	Australia	South Africa	India	Brazil
AIDS cases	103,533[a]	2,000[b]	730[c]	90,000[f]	80.000[k]	16,200[d]
HIV cases	650,000[l]	30,000[m]	11,080[e]	3,600,000[f]	21,000,000[g]	550,000[n]
Treatment costs/yr	$6,000[h]	$51[b]	$33.7[i]	$100[j]	NA	$800[o]

a = 180, b = 181, c = 182, d = 143, e = 141, f = 183, g = 184] h = 185, i = 186, j = 187, k= 188, l= 189, m= 190, n= 191, o= 192.

However, U.K. plant communities, such as grazed mesic grasslands and native *Pinus sylvestris* woodlands, contain no alien plant species.[17]

U.K. croplands and gardens contain 43% alien weeds.[17] In U.K. agriculture, weeds cause a reduction of about 10% in crop yields, but in some crops losses can be as high as 32%.[18,19] In economic terms, about $3.2 billion in total potential crop production is lost annually because of weed infestations. Given that about 43% of the weeds are alien, it is likely that $1.4 billion of the crop losses are caused by alien weeds (Table 17.2).

In Australia, some 60% of the weeds in crops are alien, based on a survey of major weeds in cereal crops.[20] The introduced blackberry (*Rubus proceus*) from Asia alone is causing $77 million a year in damage to crop production.[21] A total of 463 exotic grasses and legumes were intentionally introduced for forage; however, only four species proved beneficial for pasture and did not end up as weeds.[22] Indirect and direct losses due to pasture weeds are estimated to be $970 million a year.[23] Weeds cause an estimated $4 billion a year in total damage to cropland and pastures combined.[21] Since 60% of these weeds are alien, they account for about $2.4 billion per year in losses to agriculture[24] (Table 17.2).

In South Africa, the reduction in crop production due to all weeds is 16.6%,[19] at a cost of about $2.2 billion per year of potential production. Assuming that 67% of the weeds in the crops are alien,[25] these species account for total crop losses of about $1.5 billion a year (Table 17.2). Two of the most serious alien weeds in South African pasture lands are the shrub (*Lantana camara*) and the cactus plant (*Opuntia ficus-indica*), both introduced from Central America.[26–28]

In India, weeds are estimated to cause a 30% loss in potential crop production,[28] worth about $90 billion a year in reduced crop yields. Assuming that 42% of the weeds in crop production are alien,[29,30] the total cost of alien weeds to India is about $37.8 billion per year (Table 17.2).

Lantana camara, a major weed shrub in India, was introduced from Australia as an ornamental plant. It has invaded the majority of Indian pasture lands (13.2 million ha), as well as other areas.[28] *Lantana* is toxic to cattle, and the cost of its control is $70 per ha.[28] Since about 4% of India's land area is pasture, the damage from *Lantana* is estimated to be $924 million per year (Table 17.2).

In Brazil, alien weed species now make up 75% of the weed species in crop production areas.[31] Alien weeds destroy an estimated 13.4% of the country's crop and pasture production,[19] causing about $17 billion a year in losses (Table 17.2). These and other invasive plants change key natural ecosystems, alter fire regimes, and reduce the resources available to native animals.

17.4.2 Vertebrate pests

The English or house sparrow (*Passer domesticus*) and the European starling (*Sturnus vulgaris*) were both introduced into the United States. Both birds have become agricultural pests, together causing an estimated $1 billion a year in crop damages[4] (Table 17.2).

The European rabbit (*Oryctolagus cuniculus*) is abundant in the United Kingdom and Australia. U.K. rabbit densities may reach 30 per ha.[32] The animals are reported to reduce wheat production from 5 to 8% and livestock forage production by about 20%.[33] Assuming a conservative 10 rabbits per ha on cropland, where each rabbit causes $11 of damage per year,[32] the total crop damage from European rabbits amounts to about $800 million a year. Rabbits also do $400 million a year in damage to pastures. Thus the total damage from the European rabbit in the United Kingdom comes to $1.2 billion a year (Table 17.2).

In Australia, European rabbits also damage forage, causing losses that range from $90 million to $100 million per year.[34] Approximately 15 rabbits consume the equivalent pasture forage needed by one sheep (*Ovis aries*).[34] The impact on sheep production per year is estimated to be $110 million, including reduced sheep production and the cost of rabbit control. Total costs of rabbit damage to various aspects of agriculture are estimated to be $200 million per year (Table 17.2), but this does not include the land degradation caused by these animals.

17.4.3 Insect and mite pests

Pest insects and mites destroy about 13% of potential crop production, representing a value of about $33 billion in U.S. crops.[35] Based on the fact that about 40% of these pests are alien species,[12] the alien pests probably cause about $15.9 billion in crop losses each year (Table 17.2).

Furthermore, about 360 alien insect and mite species have become established in U.S. forests.[36] Insects cause the loss of approximately 9% of forest products, amounting to $7 billion per year.[2,37] Because 30% of the pests are alien species, annual losses attributed to them are about $2.1 billion per year (Table 17.2).

An estimated 1500 species of arthropods in the United Kingdom cause economic damage; about 30% of these are alien species.[38,39] Each year, arthropods damage or destroy approximately $3.2 billion in crops in the United Kingdom, based on 10% crop losses.[19] With about 30% of the losses in crops due to alien arthropods, the loss attributed to them amounts to $960 million per year (Table 17.2).

An estimated 36% of the pest arthropods in Australia are alien species.[40] The gross potential crop production in Australia is estimated at $24 billion per year. Crop losses due to insects and mites in Australia are estimated to be 10.7% of potential production.[19] Based on total crop losses to arthropods of about $2.6 billion per year, alien pests account for crop losses of about $936 million per year (Table 17.2).

Insect and mite pests in South Africa cause losses of 16.7%[19] of potential crop production each year, a portion worth $2.3 billion a year. Approximately 45% of the insect and mite pests are alien species[41]; thus the economic crop losses caused by introduced arthropods in South Africa are estimated to be $1 billion a year (Table 17.2).

Several hundred arthropod species in India are crop pests. Approximately 30% of the insect and mite crop pest species are alien.[42,43] Arthropods as a group reduce potential crop production by 18.7% in India.[19] Based on total potential crop production in India, crop losses to alien arthropods total $16.8 billion a year (Table 17.2).

In Brazil, about 14.4% of potential crop production is destroyed by insects and mites.[19] Approximately 35% of these species are alien.[31] The crop loss caused by alien insects and mites is estimated to be $8.5 billion a year (Table 17.2).

17.4.4 Plant pathogens

U.S. crop losses due to plant pathogens total approximately $33 billion per year.[2,35] Since 65% of all plant pathogens are alien species,[12] an estimated $23.5 billion a year can be attributed to alien plant pathogens (Table 17.2).

In U.S. forests, more than 20 non-indigenous species of plant pathogens attack woody plants.[36] Approximately 9% — a total of $7 billion — of forest products are lost annually due to plant pathogens.[2,37] Assuming that the proportion of alien plant pathogens in forests is similar to that of introduced insects, or about 30%, then approximately $2.1 billion in forest products are lost each year to non-indigenous plant pathogens in the United States (Table 17.2).

In the United Kingdom, an estimated 74% of the plant pathogens are introduced species.[44] Most of these alien plant pathogens were brought into the United Kingdom with seeds and other crop parts needed for agriculture. The economic loss due to plant pathogens amounts to 8.3% of potential production, or about $2.7 billion a year.[19] If 74% of the losses are due to alien plant pathogens, then about $2 billion a year in damages are associated with alien plant pathogens attacking crops (Table 17.2).

Total potential crop production in Australia is approximately $22 billion a year, with about 15.2% of crop losses being attributed to plant pathogens.[19] The economic losses from all plant pathogens is about $3.3 billion a year. Because a large number of plant pathogens are introduced when crop seeds and other plant parts are brought in, an estimated 82% of all crop plant pathogens are alien species (based on plant pathogens in field crops).[45] With 82% of Australian plant pathogens being alien, about $3 billion worth of crops are lost each year due to alien plant pathogens (Table 17.2).

Based on an assessment of diseases of fruits and vegetables,[46,47] approximately 85% of the plant pathogens attacking crops in South Africa are considered to be introduced. Most of these pathogens came in with crop introductions. In total, plant pathogens in South Africa cause an estimated 15.6%,[19] or $2.1 billion a year, of loss of potential crop production. Since 85% of the pathogens are alien, about $1.8 billion per year in crop losses is due to alien species.

In India, plant pathogens reduce potential crop production by approximately 16%, for a total of $48 billion per year.[48] Approximately 30,000 species of plant pathogens attack Indian crops, including 23,000 species of fungi[49] and 650 species of plant viruses.[50] Approximately 74% of the major plant pathogens in India are considered alien species, based on the major plant pathogens in vegetable crops.[51] The estimated cost of alien plant pathogens to Indian crops amounts to about $35.5 billion per year (Table 17.2).

About 75% of the plant pathogens attacking Brazilian crops are considered alien species.[31] Most of these were introduced with crops. Overall, plant pathogens cause a crop loss of about 13.5% each year.[19] Estimated losses from alien plant pathogens total about $17.1 billion a year (Table 17.2).

17.5 Environmental damage and control costs due to alien species

Many of the approximately 120,000 species of plants, animals, and microbes that have invaded the United States, the United Kingdom, Australia, South Africa, India, and Brazil cause a wide array of environmental and economic damage to both managed and natural ecosystems (Table 17.1). In some cases, an alien species can cause extensive extinctions — the brown tree snake (*Boiga irregularis*), for example, caused the extinction of more than 75% of one group of species on the island of Guam.[4,52]

17.5.1 Plants

Most alien plants now established in the United States were introduced for food, fiber, or ornamental purposes. For example, of the approximately 25,000 alien plant species (mostly ornamentals) that have been brought into Florida for cultivation, more than 900 have escaped and become established in surrounding natural ecosystems.[53–55]

About 5000 alien plants have become established in U.S. natural ecosystems, displacing several native plant species.[56] This is particularly true of the alien weeds that are invading approximately 700,000 ha per year of the wildlife habitats in the United States.[15]

One of these pest weeds is the European purple loosestrife (*Lythrum salicaria*), which was introduced in the early 19th century as an ornamental plant.[57] It has been spreading at a rate of 115,000 ha per year and is changing the basic structure of most of the wetlands it has invaded.[58] Some $45 million is spent on control of purple loosestrife each year[59] (Table 17.3).

The presence of alien aquatic plants, such as hydrilla (*Hydrilla verticillata*), water hyacinth (*Eichhornia crassipes*; native to South America), and water lettuce (*Pistia stratiotes*), alter the habitats of fish and other aquatic species, choke waterways, alter nutrient cycles, and reduce the recreational value of rivers and lakes. Florida spends about $14.5 million each year to control hydrilla.[60] Despite this large expenditure, hydrilla infestations in two Florida lakes have prevented recreational use, causing an annual loss of $10 million.[60] In the United States, a total of $100 million is invested annually in the control of alien aquatic weed species[61] (Table 17.3).

Water hyacinth is also a major weed in South Africa, where it is reducing already scarce water resources.[62] More than $25 million per year is spent on controlling water hyacinth, and water lettuce is causing damage valued at $15 million per year.[63] In Cape Town, invading woody species are estimated to reduce the total water supply by 30%.[64] The economic investment of the program Working for Water totals $50 million a year.[65] In addition, more than $5 million a year is being spent to prevent future alien plant invasions in South Africa.[66]

Of the 27,515 plant species identified in the United Kingdom, only 1515 are considered to be native[67] (Table 17.1). More than 80% of the alien plant species in the United Kingdom are established in disturbed habitats.[16,67]

Many of the alien plant species introduced into Australia have become weeds and have invaded a wide range of environments. These invasive plants are reducing yields in crops and pastures and are changing the natural environment.[68]

Of the 55,000 known plant species in Brazil,[69] an estimated 21.1% (11,605) are alien species.[70] Introduced grass species are having significant negative impacts upon Brazil's ecosystems, because they displace native grasses and make the ecosystem more susceptible to fires than native grasses do.[71]

17.5.2 Mammals

The proportion of alien mammals that have been introduced in the six nations studied range from 6% in the United States to 31% in the United Kingdom (Table 17.1). Domestic mammal introductions include dogs (*Canis familiaris*), cats, cattle, horses (*Equus caballus*), sheep, pigs, and others. Other species intentionally or accidentally introduced include the house mouse (Mus musculus), the European rabbit, the brown rat (*Rattus norvegicus*), and the black rat (*Rattus rattus*).[52,72]

Feral pigs, native to Eurasia and North Africa, are a serious problem in many parts of the world, including the United States and Australia. The number of alien feral pigs in

the United States is estimated to be 4 million[4]; in Australia, pigs range from 4 million to 20 million.[34] Feral pigs cause soil erosion; they damage agricultural crops, fences, native plants, and animals; and they pose a threat to livestock and humans. They spread various animal diseases, including tuberculosis, brucellosis, rabies, and foot-and-mouth disease.[72,73] Feral pigs cause an estimated $800.5 million per year in damages in the United States[4] and at least $80 million in Australia[34] (Table 17.3).

Many other small mammals have been introduced into most, if not all, nations in the world. These species include a number of rodents, such as the European black rat, the brown or Asiatic rat, the house mouse, the European rabbit, and the domestic cat and dog.

Some introduced rodents have become serious pests on farms, in industries, and in homes.[74] On farms, rats and mice are particularly abundant and destructive. The United States has an estimated 1.25 billion rats,[4] while India harbors approximately 2.5 billion.[75] In the United States, the best estimate suggests that an individual adult rat causes $15 of damage per year[4]; in India, the estimate is that each rat causes at least $10 per year in damage. In sum, rats cause $19 billion per year in damage in the United States, and about $25 billion per year in India (Table 17.3). Losses from rats based on the damage they cause in other nations are estimated in Table 17.3. Although no economic data are available, in India rats bite about 20,000 people per year, resulting in admittances to hospitals.[76] Also, rats are major vectors for and carriers of more than 38 human and livestock diseases in India.[77]

There are an estimated 63 million pet cats in the United States[78] and as many as 30 million feral cats.[79] Cats prey on native birds and on small native mammals, amphibians, and reptiles.[80] Assuming that eight birds are killed per feral cat each year,[81] some 240 million U.S. birds are killed per year by feral cats.[4] Each adult bird is valued at $30. This cost of a 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, the EPA values each small, immature fish at $10; certainly an adult bird has a value three times that of a small, immature fish.[37] Pet cats were estimated to kill another 326 million birds.[4] Therefore the total damage to the U.S. bird population by feral and pet cats is approximately $17 billion per year. This cost does not include small mammals, amphibians, and reptiles that are killed by feral and pet cats.[80]

In Australia, feral cats are also a serious problem, killing native bird, mammal, marsupial, and amphibian populations. There are an estimated 3 million pet cats and 18 million feral cats in Australia.[82] The cats are believed to have eliminated 23 native Australian species of animals.[83,84] Assuming that each of the 18 million feral cats kills eight birds per year, and that the minimum value of a bird is $30,[4] then the total impact from cats is $4.3 billion per year (Table 17.2).

Pet cats and feral cats are also a serious problem in South Africa. For example, on Prince Edward Island, feral cats prey on native birds, causing significant problems with the burrowing petrels (*Procellaria* sp.).[63] An estimated $1.3 million was allocated for cat control over a 7-year period on Prince Edward Island alone, where each cat killed approximately 210 birds per year.[63]

Cats and dogs are also a serious problem in most other nations, but reliable data are not available to estimate their impacts.

17.5.3 Birds

Three of the most common bird-pest invaders worldwide are the common pigeon (*Columba livia*), the English sparrow, and the European starling. These three species, plus other invading bird species, cause a total of $2.4 billion per year in damage in the six nations investigated (Tables 17.2 and 17.3).

A total of 97 of the 1000 bird species in the United States are alien.[85] Of the 97 introduced U.S. bird species, only 5% are considered beneficial, while more than half (56%) are pests.[85] One example is the pigeon, which was intentionally introduced into the United States,[86,87] where it now causes extensive damage totaling $1.1 billion per year[4] (Table 17.3).

Of the 542 species of birds in the United Kingdom, 47 are alien.[88] Pigeons are a particularly serious problem, because they foul buildings, statues, cars, and sometimes pedestrians. On farms they consume grains,[89] causing production and other economic losses. They are also responsible for transmission of at least three poultry diseases, including Newcastle disease.[90–92] Pigeon damage in the United Kingdom is estimated to be at least $270 million per year (Table 17.3).

The number of alien bird species invading the other four nations studied are listed in Table 17.1, but there are no economic data available for the other countries.

17.5.4 Amphibians and reptiles

Although amphibians and reptiles introduced into the United States number only about 53, the negative ecological impacts from these few species have been enormous.[93,94] All of these species inhabit states where it seldom freezes; Florida is now host to 30 species, and Hawaii to 12.[93,94]

The brown tree snake was accidentally introduced to snake-free Guam immediately after World War II when military equipment was moved onto the island.[95] Soon the snake population reached densities of 100 per ha, dramatically reducing native bird, mammal, and lizard populations, as well as causing major problems for small farms and pet owners. Of the 13 species of native forest birds originally found on Guam, only three species still exist in the wild.[96] The snake often crawls up utility poles and has caused a total of 1500 power outages on the island. With about 86 outages per year, a conservative estimate of the cost of the power outages alone is $1 million a year.

In addition, the brown tree snake is slightly venomous, and it causes public health problems, especially when it bites children. At one Guam hospital, bitten infants required hospitalization and intensive care at a total cost of $25,000 per year.[97]

Then there's the cost of endangered species recovery efforts, environmental planning related to snake containment on Guam, and other programs directly stemming from the snake's invasion, which together exceed $1 million per year. In addition, up to $2 million per year is invested in research and control of this serious pest.[97] Hawaii's concern about the snake has prompted the federal government to invest $1.6 million per year in brown tree snake control.[98] Thus, the total cost for the brown tree snake is more than $5.6 million per year (Table 17.3).

There are about 700 species of reptiles and amphibians in Australia, although only two have been introduced.[99] One of these introduced species, the cane toad (*Bufo marinus*), from South America, was introduced as a biological control agent for insect pests in sugarcane.[99] However, the toad has become a pest itself, because it is poisonous to dogs, cats, and other mammals that attack it.[100]

In South Africa, alien species account for 13 of the 299 total reptile species and 11 of the 95 amphibian species.[101] One introduced turtle species is the red-eared slider (*Chrysemys scripta-elegans*) from North America. This turtle has become a major threat to the 12 indigenous terrapin species.[102]

17.5.5 Fish

A total of 138 non-indigenous fish species have been introduced into the United States.[103–105] Most of these introduced fish have been established in states with mild cli-

mates, such as Florida (50 species)[105] and California (56 species).[106] In Hawaii, 33 non-indigenous freshwater fish species have become established.[107] Forty-four native U.S. species of fish are threatened or endangered because of non-indigenous fish.[108] An additional 27 species of native U.S. fish are negatively affected by introductions.[108]

Although some native fish species are merely reduced in numbers by non-indigenous species, others are forced into extinction or become hybridized with the invaders. Some alien fish have provided benefits by improving the sport fishing industry. However, other alien fish species have hurt this industry. Sport fishing contributes $69 billion a year to the economy of the United States.[2,109] Based on that estimate, the economic losses from alien fishes is approximately $1 billion annually[2,4] (Table 17.3).

Most of the alien fish species in South Africa are regarded as pests.[110] In addition, seven alien parasitic diseases of fish have been introduced into native fish populations along with the alien fish species.[111] Although the introduction of some sport fish, such as rainbow trout (*Oncorhynchus mykiss*) and largemouth bass (*Micropterus salmoides*), both native to North America, may be somewhat beneficial to the sport-fishing industry, they are also known to have negative impacts on native fish. Introduced species such as carp (*Cyprimus carpio*), bass, and trout threaten about 60% of the endemic freshwater fishes in South Africa.[112] In total, alien fish are responsible for the reduction or local extinction of at least 11 species of fish in South Africa.[110]

17.5.6 Arthropods

Approximately 4600 arthropod species (2582 species in Hawaii and approximately 2000 in the continental United States) have been introduced into the United States. More than 95% of these introductions were accidental, when species entered with plants or in soil and water ballast from ships.

The introduced balsam woolly adelgid (*Adelges piceae*) inflicts severe damage in native balsam–fir forest ecosystems.[111] According to Alsop and Laughlin,[112] this aphid is destroying the old-growth spruce–fir forest in many regions. Over a 20-year period, *A. piceae* has spread throughout the southern Appalachians and has destroyed up to 95% of the Fraser firs (*Abies fraseri*).[113] Alsop and Laughlin[112] report the loss of two native bird species and the invasion of three other species as a result of adelgid-mediated forest death.

Other introduced insect species have become pests of U.S. livestock and wildlife. For example, the red imported fire ant (*Solenopsis invicta*) from South America kills poultry chicks, lizards, snakes, and ground-nesting birds.[114] A 34% decrease in swallow (*Hirundinidae* spp.) nesting success, as well as a decline in the northern bobwhite quail (*Colinus virginianus*) populations, was caused by these ants.[115] The estimated damage to livestock, wildlife, and public health caused by fire ants in Texas is about $300 million a year. An additional $200 million is invested in control per year.[116,117] Assuming equal damages in several other ant-infested southern states, fire ant damage totals approximately $1 billion per year in the United States (Table 17.3).

In addition, the Formosan termite (*Coptotermes formosanus*) is reported to cause approximately $1 billion per year worth of damage in the southern United States, especially in the New Orleans region.[118]

The European green crab (*Carcinus maenas*) has been associated with the demise of the soft-shell clam (*Mya arenaria*) industry in New England and Nova Scotia.[119] It also destroys commercial shellfish beds and preys on large numbers of native oysters and crabs.[119] The annual estimated economic impact of the green crab is $44 million a year.[119] The crab has also invaded ecosystems in Australia and South Africa.[120]

An estimated 80,000 species of insects, 6000 species of spiders, and numerous other arthropod species exist in South Africa.[121,122] One of the most serious invaders is the

Argentine ant (*Linepithema humile*), which is causing major problems by destroying native vegetation, including endangered plants.[111] The same ant is also negatively affecting native ants and other beneficial species of arthropods.[123]

17.5.7 Mollusks

Eighty-eight species of mollusks have been introduced and become established in U.S. aquatic ecosystems.[61] Two of the most serious pests are the zebra mussel (*Dreissena polymorpha*) and the Asian clam (*Corbicula fluminea*).

The European zebra mussel was first found in Detroit's Lake St. Clair, having gained entrance via ballast water released in the Great Lakes by ships that traveled from Europe.[124] The zebra mussel has spread into most of the aquatic ecosystems in the eastern United States and is expected to invade most freshwater habitats throughout the nation.[124] Large mussel populations reduce food and oxygen for native fauna; mussel densities as high as 700,000 per m^2 have been recorded.[125] In addition, zebra mussels have been observed completely covering native mussels, clams, and snails, thereby further threatening the survival of native species.[124,125] Zebra mussels also invade and clog water intake pipes at water filtration and electric generating plants. It was estimated that this species would cause $5 billion a year in damage and associated control costs by the year 2000.[126]

Though the Asian clam grows and disperses less rapidly than the zebra mussel, it also causes significant fouling problems and threatens native species. Costs associated with the damage it causes are about $1 billion a year[61,127] (Table 17.3).

The introduced shipworm (*Teredo navalis*) in San Francisco Bay has been causing serious damage to docks and ships since the early 1990s. Currently, damage is estimated to be about $205 million a year[128] (Table 17.3).

17.6 Livestock pests

Microbes and other parasites were introduced when various species of livestock were brought into the six nations under consideration. In addition to the hundreds of pest microbes and parasites that have already been introduced, there are more than 60 additional microbes and parasites that could easily invade the United States and become serious pests to U.S. livestock.[129] A conservative estimate of the current losses to U.S. livestock from alien microbes and parasites is approximately $3 billion per year[130] (Table 17.3).

In Australia, there are an estimated 44 alien diseases of animals that could infect livestock if they gained entrance.[132] Already, three alien insect and mite species are causing $228 million a year in damage to the wool industry alone[133] (Table 17.3).

In India, there are about 50 alien diseases of livestock and wildlife that are causing significant losses, including foot-and-mouth disease.[134] During 8 months in 1996, nearly 50,000 cases of foot-and-mouth disease were reported,[135] with treatment costs of about $17,000.[48]

Several serious alien livestock diseases in South Africa, including tuberculosis, brucellosis East Coast fever, anthrax, and rinderpest are infecting livestock, wildlife, and other animals.[136] Estimates are that brucellosis alone is responsible for losses amounting to $100 million a year[137] (Table 17.3).

In Brazil and other Latin American countries, imported bovine tuberculosis (bovine TB) has become a serious threat to the development of the beef and dairy industries. Losses to bovine TB are reported to be approximately $63 million a year.[137]

17.7 Human diseases

17.7.1 AIDS, influenza, and syphilis

Perhaps the most notorious of all alien human diseases is acquired immune deficiency syndrome (AIDS), which originated in central Africa. Since the early 1980s the disease has spread to all inhabited parts of the globe. The number of cases of AIDS and HIV (human immunodeficiency virus) infections and treatment costs in the United States, the United Kingdom, Australia, South Africa, India, and Brazil are shown in Table 17.4.

New influenza strains, originating in the Far East, quickly spread to the United States and other nations. The influenza strains are reported to cause 5 to 6% of all deaths in 121 U.S. cities.[138] Costs of hospitalizations for a single outbreak of an influenza such as type A can exceed $300 million per year.[139] In total, AIDS and influenza take the lives of more than 40,000 people each year in the United States, and treatment costs for these diseases, plus for syphilis, total approximately $6.5 billion each year, and that does not include the cost of any other alien diseases (Table 17.3).

New influenza strains in the United Kingdom are reported to cause from 3000 to 4000 deaths a year.[140] In total, AIDS and influenza take the lives of approximately 4000 people each year in the United Kingdom, and treatment costs total approximately $1 billion a year, based on extrapolated data from the United States[4] (Table 17.3).

New influenza strains in Australia are reported to cause about 210 deaths a year.[140] In India, influenza cases totaled 3 million in 1984.[140]

17.7.2 Other diseases

Several other non-indigenous diseases infect humans in Brazil, including malaria, cholera, yellow fever, and dengue fever.[141,142] The numbers of people infected include: cholera, 2167; malaria, 425,000[142]; and dengue, 96,100.[143] If we assume that all of these infected people are hospitalized and that the average cost per year per person for hospitalization from these diseases in Brazil is $213,[143] then a minimum cost for these non-indigenous diseases is $133 million a year. In addition, the Brazilian government plans on spending about $1.4 billion annually to eradicate the *Aedes aegypti* mosquito, the vector of dengue fever and yellow fever[142] (Table 17.3).

Human disease transfers from one region to another continue to increase because of population growth, high population densities, rapid transportation, and the encroachment of civilization into new ecosystems.

17.8 Control and future implications

The economic damages associated with non-indigenous species invasions in the nations in the six continents total more than $336 billion per year. Of this, control costs account for more than $30 billion. Most of the control costs are associated with agricultural production.[35]

Most attempts at eradication have failed once the invading species has become well established. In the United States, the only pest species that has been eradicated has been the Mediterranean fruit fly (*Ceratitis capitata*) in Florida. The fly has invaded Florida at least three times and has been eradicated each time as a result of concerted efforts by the U.S. Department of Agriculture and the Florida Department of Agriculture.

In Britain, efforts are being made to eradicate the introduced muskrat (*Ondatra zibethicus*) and coypu (*Myocaster coypus*).[144] The populations have been significantly reduced, but the eradication effort has yet to succeed.[145]

The number of invading species worldwide have been increasing rapidly. For example, in the San Francisco Bay and Delta region, there has been a tenfold increase in the number of invading species since 1900.[146] With more people traveling and more goods moving from one country to another, there is greater opportunity for increasing numbers of species to invade most countries. There is a critical need for strict legislation to help prevent non-native species invasions, and for a major effort to educate the public concerning the dangers of invading species.

17.9 Conclusion

More than 120,000 non-indigenous species of plants, animals, and microbes have invaded the United States, the United Kingdom, Australia, India, South Africa, and Brazil (Table 17.1). An estimated 20 to 30% of the introduced species are pests and cause major environmental problems. Although relatively few of these species become serious pests, some species inflict significant damage to natural and managed ecosystems and cause public health problems. A variety of ecological factors allow alien species to become abundant and to emerge as ecological threats in their new ecosystem. These include alien plant or animal species introduced without their natural enemies (e.g., purple loosestrife); the development of new associations between alien parasite and host (e.g., the HIV virus and humans); effective predators in a new ecosystem (e.g., feral cats); artificial or disturbed habitats that provide favorable ecosystems for the invasive aliens (e.g., weeds in crop and lawn habitats); and invasion by some highly adaptable and successful alien species (e.g., the water hyacinth and the zebra mussel).

The study documents that the economic damage associated with non-indigenous species invasions in the six selected nations totals more than $336 billion per year. Precise economic costs associated with some of the most ecologically damaging alien species are not available. Cats and pigs, for example, have been responsible for the extinction of various animal species. Yet for these pest animals, only minimal cost data are known. Also, it is impossible to assess the value of a species that has been forced to extinction. If monetary values could be assigned to species extinctions, losses in biodiversity, ecosystem services, and aesthetics, then the cost of destructive non-indigenous species would undoubtedly be several times higher than the reported $336 billion. Yet even this conservatively stated economic loss indicates that alien species are exacting a significant environmental and economic toll worldwide.

The calculated dollar cost per capita for the losses incurred due to biological invaders in the six nations investigated were approximately $240 per year. Assuming similar costs worldwide, damages from invasive species would total more than $1.4 trillion a year. Based on an estimated $31 trillion in world GNP,[5] the $1.4 trillion in losses from invasive species represents nearly 5% of the world economy.

Nearly all crop and livestock species are non-indigenous. These alien crops (e.g., corn and wheat) and livestock (e.g., cattle and poultry) are vital to maintaining world agriculture and the global food system. However, these benefits do not diminish the enormous negative impacts of other non-indigenous species on agricultural and other managed and natural ecosystems.

A real challenge lies ahead in preventing further damage from invading alien species to natural and managed ecosystems worldwide, especially given the current rapid human population growth and related activities. The United States has taken a few steps in an effort to protect the environment from biological invaders. For example, President Clinton issued an executive order on Feb. 2, 1999, creating an interagency National Invasive Species Council and allocating $28 million to produce a plan within 18 months to mobilize the federal government to defend against non-indigenous species invasions. In addition,

Australia, South Africa, India, Brazil, and the United Kingdom all have specific programs in place to prevent invasions of alien species in their countries. This suggests that a few million dollars spent on preventing future introduction of potentially harmful alien species in the United States and other nations will prevent billions of dollars in losses to agriculture, forestry, and other aspects of managed and natural environments worldwide.

Specific legislation is needed in all countries to slow or prevent non-native species introductions. All introductions of non-native plants, animals, and microbes, for whatever purposes — including agriculture, hunting, tourism, pets, recreation, and research — should be strictly regulated.[147] In addition, the government should make every effort to inform the public concerning the serious environmental and economic threats that are associated with alien species introductions.

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