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

David Pimentel*, S. McNair, J. Janecka, J. Wightman, C. Simmonds, C. O'Connell, E. Wong, L. Russel, J. Zern, T. Aquino, T. Tsomondo

College of Agriculture and Life Sciences, Cornell University, Ithaca, NY 14850-0901, USA

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Abstract

Over 120,000 non-native species of plants, animals and microbes have invaded the United States, United Kingdom, Australia, South Africa, India, and Brazil, and many have caused major economic losses in agriculture and forestry as well as negatively impacting ecological integrity. Some introduced species, like corn (*Zea mays* L.), wheat (*Triticum* spp.), rice (*Oryza sativa* L.), plantation forests, domestic chicken (*Gallus* spp.), cattle (*Bos taurus*), and others, are beneficial and provide more than 98% of the world's food supply. Precise economic costs associated with some of the most ecologically damaging alien species are not available. Cats (*Felis cattus*) and pigs (*Sus scrofa*), for example, are responsible for the extinction of various animal species, however, it is impossible to assign monetary values to species forced to extinction. The estimate is that non-native species invasions in the six nations are causing more than US$ 314 billion per year in damages.

Keywords: Plants; Animals; Alien; Economic; Ecology; Environment; Agriculture; Non-indigenous

1. Introduction

Quantifying the environmental damage and loss of biodiversity due to alien species invasions worldwide is complicated by the fact that some 1.5 million species of the estimated 10 million species on earth are identified and described (Raven and Johnson, 1992). The total number of introduced species in the United States, United Kingdom, Australia, South Africa, India, and Brazil range from about 2000 to 50,000 species (Table 1). Many native species are threatened by competition and predation from invaders, while many other species are endangered by hybridization with alien species and/or major ecosystem changes caused by these species. Nonetheless, more than 120,000 known species of plants, animals, and microbes have invaded these six nations studied; these provide a base to assess several environmental threats associated with these alien species (Table 1).

Given the number of species that have invaded these six nations studied, it was estimated that 480,000 alien species have been introduced into the varied ecosystems on earth. Many such introduced species, like corn, wheat, rice, plantation forests, domestic chicken, cattle, and others are beneficial and now provide more than 98% of the world food supply with a value of more than US$ 5 trillion per year (USBC, 1998). All crop and livestock species originated in various geographic regions of the earth, such as the chicken from south eastern Asia. Other alien species

* Corresponding author. Tel.: +607-255-2212; fax: +607-255-0939.
E-mail address: dp18@cornell.edu (D. Pimentel).

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Table 1
Species number per category in the United States, United Kingdom, Australia, South Africa, India, and Brazil[a]

Category	United States		United Kingdom		Australia		South Africa		India		Brazil	
	Total species number	Alien species number	Total species number	Alien species number	Total species number	Alien species number	Total species number	Alien species number	Total species number	Alien species number	Total species number	Alien species number
Plants	42000 a	25000 a	27515 f	26000 f	20000 l	1952 m	24000 q	8750 r	45000 y	18000 z	55000 p	11605 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	650 b	97 a	542 h	47 h	850 n	70 n	725 t	8 t	1221 bb	4 cc	1635 ii	3 ll
Reptiles and amphibians	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	2546 ee	300 ff	3000 mm	76 ii
Arthropods	650000 e	4500 a	24700 k	1700 k	85920 ii	150 ii	86000 w,x	NA	54430 gg	1100 hh	1000000 nn	NA
Microbes	134644 d	20000 e	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

[a] a: Pimentel et al., 2000; b: WRI, 1998; c: Layne, 1997; d: Palmer and Fowler, 1975; McKnight and McKnight, 1987; Horst, 1990; Fauquet, 1994; LaRoe et al., 1995; Hawksworth et al., 1995; e: estimated; f: Crawley et al., 1996; g: Matthews, 1982; Baker, 1990; h: Gooders, 1982; i: Frazer, 1983; j: Cacutt, 1979; Maitland and Campbell, 1992; k: van Lenteren, 1995; l: Emmerson and McCulloch, 1994; m: Davis et al., 1995; n: Long, 1981; Kitching, 1986; o: Fox, 1995; p: WRI, 1998; q: Russel et al., 1987; r: van Wilgen and van Wyk, 1999; s: Kruger et al., 1989; t: Cock and Koch, 1991; u: Siegfried, 1989; v: Stuart and Adams, 1990; w: Anon., 1989; x: South Africa, 1998; y: Sharma et al., 1993; z: Saxena, 1991; aa: Species Diversity, 1998; Mammals Checklist for India, 1998; bb: WCMC, 1998; cc: Saini and Kaur, 1986; dd: www.emb/-heidelbergde/vetz/living.~reptiles.htul, 1998; WCMC, 1998; ee: WCMC, 1998; ff: Talwar and Jhigran, 1991; gg: Ghosh, 1994; hh: Gupta, 1985; ii: Vitousek et al., 1997; jj: Harcourt and Sayes, 1996; kk: Mares et al., 1989 (calculation based on data); ll: Sick, 1993; mm: Brazil Diversity, 1998; nn: G.S. Rodrigues, Personal Communication, Embrapa Meio Ambiente, Brazil, 1999.

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 negatively impact ecological integrity (Mack and D'Antonio, 1998; Pimentel et al., 2000).

In the recent past, the rate and risk associated with alien species introductions have increased enormously because human population growth and human activities altering the environment have escalated rapidly (Pimentel et al., 2000). Currently, there are 6 billion humans on earth (PRB, 1998). Large numbers of humans are traveling faster and farther while more goods and materials are being traded among nations (Bryan, 1996; USBC, 1998). These human activities are increasing 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 US, UK, Australia, South Africa, India, and Brazil. Although these nations have some of the best national data in the world, the total invading species are still unknown, making the assessment incomplete and extremely difficult. In same cases, lack of data would make the economic and environmental information underestimates.

2. Methodology

The approach employed in this investigation was to assemble all the published data on available invasive species in the US, UK, Australia, South Africa, India, and Brazil. The number of alien species for each major group was totaled; these data are found in Table 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 2–4.

3. Alien species in the US, UK, Australia, South Africa, India, and Brazil

Alien species cause major environmental and economic problems worldwide. In the US about 400 of

Table 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[a]	87.4
Pastures	6.0	–	0.6	–	0.92	–	7.52
Vertebrates							
Crops	1.0[b]	1.2[c]	0.2[d]	–[e]	–	–	2.4
Arthropods							
Crops	15.9	0.96	0.94	1.0	16.8	8.5	44.1
Forests	2.1	–	–	–	–	–	2.1
Plant path							
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	6.24	4.3	91.02	42.6	28.72

[a] Pasture losses included in crop losses.
[b] Losses due to English starlings and English sparrows (Pimentel et al., 2000).
[c] Calculated damage losses from the European rabbit (see text).
[d] Emmerson and McCulloch, 1994.
[e] –: data not available.

Table 3
Environmental losses to introduced pests in the United States, United Kingdom, Australia, South Africa, India, and Brazil (billion dollars per year)[a]

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	4.400 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 i	0.118 i	–	2.333 i	10.467
Total	58.299	6.570	6.866	3.013	25.000	6.733	106.481

[a] a: a total of US$ 45 million per year in purple loosestrife control plus US$ 100 million per year in aquatic weed control (Pimentel et al., 2000); b: Pimentel et al., 2000; c: damages from cats at US$ 17 billion per year, pigs US$ 800.5 million per year, dogs US$ 250 million per year, mongooses US$ 50 million per year, and horses and burros US$ 5 million per year (Pimentel et al., 2000); d: damages from pigeons (Pimentel et al., 2000); e: damages from the brown tree snake (Pimentel et al., 2000); f: damages from invading fish species (Pimentel et al., 2000); g: damages from the imported fire ant estimated to be US$ 1 billion per year, gypsy moth US$ 11 million per year, varroa mite US$ 82 million per year, formosan termite US$ 1 billion per year, and green crab US$ 44 million per year (Pimentel et al., 2000); h: control/damaage costs from the zebra mussel, Asian clam, and shipworm (Pimentel et al., 2000); i: see text; j: about US$ 40 million per year for aquatic weed control; US$ 50 million per year for Working for Water; and US$ 5 million per year preventing plant invasions; k: estimated 4.6 rats per capita and US$ 15 damages/rat per year (Pimentel et al., 2000); l: estimated 2.7 rats per capita in India (similar estimates for South Africa and Brazil) (Vasantharaj and Kumaraswami, 1975) and US$ 10 damages/rat per year (Pimentel et al., 2000); m: estimated one cat/three people and 1/3rd are feral and each feral cat kills two birds per year, then damages are calculated to be US$ 1.2 billion per year (Pimentel et al., 2000); n: estimated 18 million feral cats in Australia (Anon., 1996) and these cats kill 144 million birds per year, then damages are calculated to be US$ 4.3 billion per year (Pimentel et al., 2000). In addition, feral pigs are causing US$ 80 million per year in damages (Emmerson and McCulloch, 1994) and mice approximately US$ 75 million per year (Redhead et al., 1991); o: estimated 0.5 pigeons/person and damages calculated to be US$ 9/pigeon per year, then damages are approximately US$ 270 million per year (Pimentel et al., 2000); p: three exotic insect and mite species cause US$ 228 million per year in damages to the wool industry (Slater et al., 1996); –: data not available.

Table 4
The number of humans with AIDS or HIV infections and health care costs (× 1 million) in the United States, United Kingdom, Australia, South Africa, India, and Brazil[a]

	United States	United Kingdom	Australia	South Africa	India	Brazil
AIDS cases	103533 a	2000 b	730 c	90000 f	80000 k	16200 d
HIV cases	650000 l	30000 m	11080 e	3600000 f	21000000 g	550000 n
Treatment costs per year	US$ 6000 h	US$ 51 b	US$ 33.7 i	US$ 100 j	NA	US$ 800 o

[a] a: CDC, 1996; b: Berridge, 1996; c: CDHFS, 1997–98; d: Nascimento, 1998; e: Australia HIV, 1999; f: South Africa, 1999; g: www.nic.in, 1998; h: USPHS, 1994; i: Hurley et al., 1995; j: Webb, 1997; k: http://www.unaids.org./highband/document/epdidemio/june98/fact sheets/index.html; l: http://www.avert.org/usastata.htm 1999; m: http://www.avert.org./statsage/htm 1999; Charles Bowman, charlesb@atp.org.uk; n: http://158.232.21.21.5/Revised/Cube_frame.html 1999; o: http:hivinsite.ucsf.edu/international/asia/latin_america/2098.3bd9.html 1999.

the 958 species on the US Threatened or Endangered Species List are considered at risk primarily because of competition with and predation by non-indigenous species (Nature Conservancy, 1996). In the Fynbos region of South Africa 80% of the threatened species are endangered because of invading alien species (Armstrong, 1995). Most plant and vertebrate animal introductions have been intentional, whereas most invertebrate and microbe introductions have been accidental (Elton, 1958). More than 120,000 species of plants, animals, and microbes have invaded the six nations investigated and many are causing a wide array of damages both to managed and natural ecosystems (Table 1). Based on data available, the percentage of the total invading species for each nation is: UK 53%, India 19%, South Africa 7%, US 6%, Australia 3%, and Brazil 1% (Table 1).

4. Crop, pasture, and forest losses

Introduced plant, animal, and microbe species cause from US$ 55 billion to 248 billion per year in losses to world agriculture (Bright, 1999).

4.1. Weeds

In crop systems, including forage crops, many intentionally introduced plant species have become weed pests (Pimentel et al., 1989). Most weeds are accidentally introduced with crop seeds, from ship-ballast soil, or from various imported plant materials (Pimentel et al., 2000).

In US agriculture, weeds cause a reduction of 12% in potential crop yields. In economic terms, this reduction represents about a US$ 33 billion loss in crop production annually, based on the crop potential value of all US crops of more than US$ 267 billion per year (USBC, 1998). Based on the estimate that about 73% of the weeds are non-indigenous (Pimentel, 1993), it is likely that about US$ 27.9 billion of these crop losses are due to introduced weeds (Table 2).

In US pastures, 45% of weeds are alien species (Pimentel, 1993). US pastures provide about US$ 10 billion in forage crops annually (USDA, 1998), and the estimated loss due to weeds is US$ 2 billion (Pimentel, 1991). Since about 45% of the weeds are alien (Pimentel, 1993), the approximate forage losses due to non-indigenous weeds are nearly US$ 1 billion per year. According to Interior Secretary Bruce Babbitt (1998), ranchers spend about US$ 5 billion per year to control invasive alien weeds in pastures and rangelands, but these weeds continue to spread (Table 2).

Most of the UK 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 (Clement and Foster, 1994; Crawley et al., 1996). An estimated 63% of the alien plant species grow in hedges and scrub areas (Crawley et al., 1996). Vegetation in rock walls and woodlands consist of about 40% alien species. However, UK plant communities like grazed, mesic grasslands and native *Pinus sylvestris* woodlands contain no alien plant species (Crawley et al., 1996).

UK croplands and gardens contain 43% alien weeds (Crawley et al., 1996). In UK agriculture, weeds cause a reduction of about 10% in crop yields, but in some crops, losses can be as high as 32% (Spedding, 1985; Oerke et al., 1994). In economic terms, about US$ 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 US$ 1.4 billion of the crop losses are caused by alien weeds (Table 2).

In Australia, some 60% of the weeds in crops are alien, based on a survey of major weeds in cereal crops (Lemerle et al., 1996). The introduced blackberry (*Rubus proceus*) from Asia is alone causing US$ 77 million per year of damage to crop production (Davis et al., 1995). 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 (Lonsdale, 1994). Indirect and direct losses due to pasture weeds are estimated to be US$ 970 million per year (Delfosse, 1993). Weeds cause an estimated US$ 4 billion per year in total damages in cropland and pastures combined (Davis et al., 1995). Since 60% of these weeds are alien, they account for about US$ 2.4 billion per year in losses to agriculture (Groves, 1991) (Table 2).

In South Africa, reductions in crop production due to all weeds is 16.6% (Oerke et al., 1994) and cost about US$ 2.2 billion per year in value of potential crop production. Assuming that 67% of the weeds in crops are alien (Bromilow, 1995), they cause total crop

losses of about US$ 1.5 billion per year (Table 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 (Cilliers and Neser, 1991; Kluge and Neser, 1991).

In India, weeds are estimated to cause a 30% loss in potential crop production (Singh, 1996) worth about US$ 90 billion per year in reduced crop yields. Assuming that 42% of the weeds in crop production are alien (Khuspe et al., 1982; Nandpuri et al., 1986), the total cost associated with them is about US$ 37.8 billion per year (Table 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) plus other areas (Singh et al., 1996). *Lantana* is toxic to cattle and the cost of its control is US$ 70 per hectare (Singh et al., 1996). Since about 4% of India's land area is pasture, the damage from *Lantana* is estimated to be US$ 924 million per year (Table 2).

In Brazil, alien weed species make up 75% of the weed species in crop production areas (Echandi et al., 1972). Alien weeds are estimated to destroy about 13.4% of crop and pasture production (Oerke et al., 1994), causing about US$ 17 billion per year in losses (Table 2). These and other invasive plants change key natural ecosystems, alter fire regimes, and reduce the resources for native animals.

4.2. Vertebrate pests

The English or house sparrow (*Passer domesticus*) and the European starling (*Sturnus vulgaris*) were both introduced into the US. Both birds have become agricultural pests, together causing an estimated US$ 1 billion per year in crop damages (Pimentel et al., 2000) (Table 2).

The European rabbit (*Oryctolagus cuniculus*) is abundant in the UK and Australia. UK rabbit densities may reach 30 per hectare (McKillop et al., 1998). They are reported to reduce wheat production from 5 to 8% and livestock forage production by about 20% (Thompson, 1994). Assuming a conservative 10 rabbits per hectare on cropland where each rabbit causes US$ 11 damage per year (McKillop et al., 1998), the total crop damages from European rabbits amounts to about US$ 800 million per year. Rabbits also damage pastures valued at US$ 400 million per year. Thus, the total damage from the European rabbit in the UK is US$ 1.2 billion per year (Table 2).

In Australia, European rabbits damage forage, causing losses that range from US$ 90 to 100 million per year (Emmerson and McCulloch, 1994). Approximately 15 rabbits consume the equivalent pasture forage needed by one sheep (*Ovis aries*) (Emmerson and McCulloch, 1994). The impact on sheep production per year is estimated to be US$ 110 million, including reduced sheep production and expenses for rabbit control. Total costs of rabbit damage to various aspects of agriculture are estimated to be US$ 200 million per year (Table 2), but this does not include the land degradation caused by these animals.

4.3. Insect and mite pests

Pest insects and mites destroy about 13% of potential crop production, representing a value of about US$ 33 billion in US crops (Pimentel, 1997). Based on the fact that about 40% of these pests are alien species (Pimentel, 1993), the alien pests probably cause about US$ 15.9 billion in crop losses each year (Table 2).

Furthermore, about 360 alien insect and mite species have become established in US forests (Liebold et al., 1995). Insects cause the loss of approximately 9% of forest products, amounting to US$ 7 billion per year (Hall and Moody, 1994; USBC, 1998). Because 30% of the pests are alien species, annual losses attributed to them is about US$ 2.1 billion per year (Table 2).

An estimated 1500 species of arthropods in the UK cause economic damage; about 30% of these are alien species (Seymour, 1989; van Lenteren, 1995). Each year arthropods damage and/or destroy approximately US$ 3.2 billion in crops in the UK, based on 10% crop losses (Oerke et al., 1994). With about 30% of the losses in crops due to alien arthropods, the loss attributed to them amounts to US$ 960 million per year (Table 2).

An estimated 36% of the pest arthropods in Australia are alien species (Woods et al., 1990). The gross potential crop production in Australia is estimated at US$ 24 billion per year. Crop losses due to insects and mites in Australia are estimated to be 10.7% of potential production (Oerke et al., 1994). Based on total crop losses to arthropods of about

US$ 2.6 billion per year, then alien pests account for crop losses of about US$ 936 million per year (Table 2).

Insect and mite pests in South Africa cause 16.7% (Oerke et al., 1994), or US$ 2.3 billion per year, in losses of potential crop production each year. Approximately 45% of the insect and mite pests are alien species (Myburgh, 1989). Thus, the economic crop losses caused by introduced arthropods in South Africa are estimated to be US$ 1 billion per year (Table 2).

Several hundred arthropod species in India are crop pests. Approximately 30% of the insect and mite crop-pest species are alien species (David and Kumaraswami, 1975; Lal, 1990). Arthropods as a group reduce potential crop production by 18.7% (Oerke et al., 1994). Based on total potential crop production in India, crop losses to alien arthropods total US$ 16.8 billion per year (Table 2).

In Brazil, about 14.4% of potential crop production is destroyed by insects and mites (Oerke et al., 1994). Approximately 35% of these species are alien (Echandi et al., 1972). The calculated crop loss caused by alien insects and mites is estimated to be US$ 8.5 billion per year (Table 2).

4.4. Plant pathogens

US crop losses due to plant pathogens total approximately US$ 33 billion per year (Pimentel, 1997; USBC, 1998). Since 65% of all plant pathogens are alien species (Pimentel, 1993), an estimated US$ 23.5 billion per year can be attributed to alien plant pathogens (Table 2).

In US forests, more than 20 non-indigenous species of plant pathogens attack woody plants (Liebold et al., 1995). Approximately 9% — a total of US$ 7 billion per year — of forest products are lost due to plant pathogens (Hall and Moody, 1994; USBC, 1998). Assuming that the proportion of alien plant pathogens in forests is similar to that of introduced insects, about 30%, then approximately US$ 2.1 billion in forest products are lost each year to non-indigenous plant pathogens in the US (Table 2).

In the UK, an estimated 74% of the plant pathogens are introduced species (Carlile, 1988). Most of these alien plant pathogens were brought into the UK 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 US$ 2.7 billion per year (Oerke et al., 1994). If 74% of the losses are due to alien plant pathogens, then about US$ 2 billion per year in damages are associated with alien plant pathogens attacking crops (Table 2).

Total potential crop production in Australia is approximately US$ 22 billion per year, with about 15.2% of crop losses due to plant pathogens (Oerke et al., 1994). The economic losses from all plant pathogens is about US$ 3.3 billion per 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 [Persley and Syme, 1990]). With 82% of Australian plant pathogens being alien, about US$ 3.0 billion per year in crops are lost due to alien plant pathogens (Table 2).

Based on an assessment of diseases of fruits and vegetables (Wager, 1956; Nel, 1985), 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% (Oerke et al., 1994) or US$ 2.1 billion per year loss of potential crop production. Since 85% of the pathogens are alien, about US$ 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 US$ 48 billion per year (Singh, 1996). Approximately 30,000 species of plant pathogens attack Indian crops, including 23,000 species of fungi (Pandotra, 1997), and 650 species of plant viruses (Patel and Patel, 1985). Approximately 74% of the major plant pathogens in India are considered alien species, based on the major plant pathogens in vegetable crops (Singh, 1985). The estimated cost of alien plant pathogens to Indian crops amounts to about US$ 35.5 billion per year (Table 2).

About 75% of the plant pathogens attacking Brazilian crops are considered alien species (Echandi et al., 1972). Most of these were introduced with crops. Overall, plant pathogens cause about 13.5% crop loss each year (Oerke et al., 1994). Estimated losses from alien plant pathogens total about US$ 17.1 billion per year (Table 2).

5. Environmental damages and control costs due to alien species

Many of the approximately 120,000 species of plants, animals, and microbes that have invaded the US, UK, Australia, South Africa, India, and Brazil cause a wide array of environmental and economic damages to both managed and natural ecosystems (Table 1). In some regions, an alien species, like the brown tree snake (*Boiga irregularis*), has caused the extinction of more than 75% of one group of species (Atkinson, 1996; Pimentel et al., 2000).

5.1. Plants

Most alien plants now established in the US were introduced for food, fiber, and/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 (Frank and McCoy, 1995; Frank et al., 1997; Simberloff et al., 1997).

About 5000 alien plants have become established in US natural ecosystems, displacing several native plant species (Morse et al., 1995). This is particularly true of the alien weeds that are invading approximately 700,000 ha per year of the US wildlife habitat (Babbitt, 1998).

One of these pest weeds is the European purple loosestrife (*Lythrum salicaria*) which was introduced in the early 19th century as an ornamental plant (Malecki et al., 1993). 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 (Thompson et al., 1987). Some US$ 45 million is spent on control of purple loosestrife each year (ATTRA, 1997) (Table 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 recreational use of rivers and lakes. In an effort to control hydrilla, Florida spends about US$ 14.5 million each year (Center et al., 1997). Despite this large expenditure, hydrilla infestations in two Florida lakes have prevented their recreational use, causing an annual loss of US$ 10 million (Center et al., 1997). In the US, a total of US$ 100 million is invested annually in the control of alien aquatic weed species (OTA, 1993) (Table 3).

Water hyacinth is also a major weed in South Africa, where it is reducing already scarce water resources (Richardson et al., 1997). More than US$ 25 million per year is spent on control of water hyacinth, plus US$ 15 million per year from damages from water lettuce (Huntley, 1996). In Cape Town, invading woody species are estimated to reduce the total water supply by 30% (Le Maitre et al., 1996). The economic investment of the program Working for Water totals US$ 50 million per year (van Wilgen et al., 1998). In addition, more than US$ 5 million per year is being spent to prevent future alien plant invasions in South Africa (Alien Plants, 1997).

Of the 27,515 total plant species identified in the UK, only 1515 species are considered to be native (Crawley et al., 1996) (Table 1). More than 80% of alien plant species in the UK are established in disturbed habitats (Clement and Foster, 1994; Crawley et al., 1996).

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 changing the natural environment (Castles, 1992).

Of the 55,000 known plant species in Brazil (WRI, 1998), an estimated 21.1% (11,605) are alien species (Vitousek et al., 1997). 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 (Nepstead and Serrao, 1991).

5.2. Mammals

The proportion of alien mammals that have been introduced in the six nations studied range from 6% in the US to 31% in the UK (Table 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*), European rabbit, brown rat (*Rattus norvegicus*), and black rat (*Rattus rattus*) (Lever, 1994; Atkinson, 1996).

Feral pigs, native to Eurasia and North Africa, are a serious problem in many parts of the world, including the US and Australia. The number of alien feral pigs in the US is estimated to be 4 million (Pimentel et al., 2000); in Australia, pigs range from 4 to 20 million (Emmerson and McCulloch, 1994). Feral pigs cause soil erosion, damage agricultural crops, fences, native plants and animals, and are a threat to livestock and humans; and they spread various animal diseases, including tuberculosis, brucellosis, rabies, and foot-and-mouth disease (Hume, 1987; Lever, 1994). Feral pigs cause an estimated US$ 800.5 million in damages in the US (Pimentel et al., 2000) and at least US$ 80 million per year in damages in Australia (Emmerson and McCulloch, 1994) (Table 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, brown or Asiatic rat, house mouse, European rabbit, and the domestic cat and dog.

Some introduced rodents have become serious pests on farms, in industries, and in homes (Layne, 1997). On farms, rats and mice are particularly abundant and destructive. The US has an estimated 1.25 billion rats (Pimentel et al., 2000) while India harbors approximately 2.5 billion total rats (Vasantharaj and Kumaraswami, 1975). In the US, the best estimate suggests that an individual adult rat causes US$ 15 of damage per year (Pimentel et al., 2000); in India, the estimate is that each rat causes at least US$ 10 per year in damages. In sum, rats cause US$ 19 billion per year in damages in the US, and about US$ 25 billion per year in damages in India (Table 3). Losses from rats based on the damages they cause in other nations are estimated in Table 3. Although no economic data are available, in India rats bite about 20,000 people per year, resulting in admittance to hospitals (Mountfort and Cubitt, 1985). Also, rats are major vectors for and carriers of more than 38 human and livestock diseases in India (Srivastava, 1987).

There are an estimated 63 million pet cats in the US (Nassar and Mosier, 1991) and as many as 30 million feral cats (Luoma, 1997). Cats prey on native birds (Fitzgerald, 1990), and small native mammals, amphibians, and reptiles (Dunn and Tessaglia, 1994). Assuming eight birds were killed per feral cat per year (McKay, 1996), then 240 million US birds are killed per year (Pimentel et al., 2000). Each adult bird was valued at US$ 30. This cost of a bird is based on the literature that reports that a bird watcher spends US$ 0.40 per bird observed, a hunter spends US$ 216 per bird shot, and specialists spend US$ 800 per bird reared for release. In addition, EPA values each small, immature fish at US$ 10, certainly an adult bird has a value three times a small, immature fish (Pimentel and Greiner, 1997). Pet cats were estimated to kill 326 million birds (Pimentel et al., 2000). Therefore, the total damage to the US bird population by feral cats is approximately US$ 17 billion per year. This cost does not include small mammals, amphibians, and reptiles that are killed by feral and pet cats (Dunn and Tessaglia, 1994).

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 (Anon., 1996). The cats are believed to have eliminated 23 native Australian species of animals (Maynard and Hawkes, 1996; Low, 1999). Assuming that each of the 18 million feral cats kills eight birds per year and that the minimum value of a bird is US$ 30 (Pimentel et al., 2000), then the total impact from cats is US$ 4.3 billion per year (Table 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.) (Huntley, 1996). An estimated US$ 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 (Huntley, 1996).

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

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 US$ 2.4 billion per year in damages in the six nations investigated (Tables 2 and 3).

A total of 97 of the 1000 bird species in the US are alien (Temple, 1992). Of the 97 introduced US bird species, only 5% are considered beneficial, while over

half (56%) are pests (Temple, 1992). One example is the pigeon, which was intentionally introduced into the US (Laycock, 1966; Roots, 1976), where it now causes numerous damages totaling US$ 1.1 billion per year (Pimentel et al., 2000) (Table 3).

Of the 542 species of birds in UK, 47 are alien species (Gooders, 1982). Pigeons are a particularly serious problem because they foul buildings, statues, cars, and sometimes pedestrians. On farms they consume grains (Long, 1981), causing production and economic losses. They are also responsible for transmission of at least three poultry diseases, including Newcastle disease (Alexander et al., 1985; Alexander and Parsons, 1986; Bevan and Bracewell, 1986). Pigeon damages in the UK are estimated to be at least US$ 270 million per year (Table 3).

The number of alien bird species invading the other four nations studied are listed in Table 1, but there are no economic data available for the other countries.

5.4. Amphibians and reptiles

Although amphibians and reptiles introduced into the US number only about 53, the negative ecological impacts from these few species have been enormous (McCoid and Kleberg, 1995; Lafferty and Page, 1997). All these species inhabit states where it seldom freezes; Florida is now host to 30 species and Hawaii to 12 (McCoid and Kleberg, 1995; Lafferty and Page, 1997).

The brown tree snake was accidentally introduced to snake-free 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 hectare, dramatically reducing native bird, mammal, and lizard populations, as well as causing major problems for small farmers and pet owners. Of the 13 species of native forest birds originally found on Guam, only three species still exist in the wild (Rodda et al., 1997). The snake crawls up utility poles and has caused a total of 1500 power outages on the island. With about 86 outages per year (BTSCP, 1996), a conservative estimate of the cost of power outages is US$ 1 million per year.

In addition, the brown tree snake is slightly venomous, and 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 US$ 25,000 per year (T. Fritts, Personal Communication, US Geological Survey, 1998). 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 are in excess of an additional US$ 1 million per year. In addition, up to US$ 2 million per year is invested in research and control of this serious pest (T. Fritts, Personal communication, 1998 federal budget, US Geological Survey, 1998). Hawaii's concern about the snake has prompted the federal government to invest US$ 1.6 million per year in brown tree snake control (Holt, 1997–1998). Thus, the total cost for the brown tree snake is more than US$ 5.6 million per year (Table 3).

There are about 700 species of reptiles and amphibians in Australia, though only two species that have been introduced (Fox, 1995). One of these introduced species, the cane toad (*Bufo marinus*) from South America, was introduced as a biological control agent for insect pests in sugar cane (Fox, 1995). However, the toad has become a pest itself because it is poisonous to dogs, cats, and other mammals that attack it (Sabath et al., 1981).

In South Africa, alien reptiles number 13 of 299 total reptile species and 11 of 95 amphibian species (Siegfried, 1989). One introduced turtle species is the red-eared slider (*Chrysemys scripta elegans)* of North America. This turtle has become a major threat to the 12 indigenous terrapin species (Boycott and Bourquin, 1988).

5.5. Fish

A total of 138 non-indigenous fish species has been introduced into the US (Courtenay et al., 1991; Courtenay, 1993, 1997). Most of these introduced fish have been established in States with mild climates, like 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 US species of fish are threatened or endangered due to non-indigenous fish (Wilcove and Bean, 1994). An additional 27 native US species of native fish are negatively affected by introductions (Wilcove and Bean, 1994).

Although some native fish species are reduced in numbers by non-indigenous species, others are forced into extinction or hybridized with others. Some alien fish have provided benefits in the improvement of sport fishing. However, other alien fish species have reduced the sport-fishing industry. Sport fishing contributes US$ 69 billion per year to the economy of the US (Bjergo et al., 1995; USBC, 1998). Based on the estimate that sport fishing is valued at US$ 69 billion per year, the economic losses due to alien fishes is estimated to be approximately US$ 1 billion annually (USBC, 1998; Pimentel et al., 2000) (Table 3).

Most of the alien fish species in South Africa are regarded as pests (Bruton and Van As, 1985). In addition, seven alien parasitic diseases of fish have been introduced into native fish populations along with the alien fish species (Macdonald et al., 1986). Although the introduction of some sport fish, like rainbow trout (*Oncorhynchus mykiss*) and large mouth bass (*Micropterus salmoides*) both native to 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 (O'Keefe et al., 1989). In total, alien fish are responsible for the reduction or local extinction of at least 11 species of fish in South Africa (Bruton and Van As, 1985).

5.6. Arthropods

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

The introduced balsam woolly adelgid (*Adelges piceae*) inflicts severe damage in balsam-fir natural forest ecosystems (Jenkins, 1998). According to Alsop and Laughlin (1991), this aphid is destroying the old-growth spruce-fir forest in many regions. Over a 20-year period, it has spread throughout the southern Appalachians and has destroyed up to 95% of the fraser firs (*Abies fraseri*) (H.S. Neufeld, Personal Communication, Appalachian State University, 1998). Alsop and Laughlin (1991) 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 US livestock and wildlife. For example, the red imported fire ant (*Solenopsis invicta*) from South America kills poultry chicks, lizards, snakes, and ground nesting birds (Vinson, 1994). 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 (Allen et al., 1995). The estimated damage to livestock, wildlife, and public health caused by fire ants in Texas is about US$ 300 million per year. An additional US$ 200 million is invested in control per year (Vinson, 1992; TAES, 1998). Assuming equal damages in several other ant-infested southern states, the fire ant damages total approximately US$ 1 billion per year in the US (Table 3).

In addition, the Formosan termite (*Coptotermes formosanus*) is reported to cause damages of approximately US$ 1 billion per year in Southern US, especially in the New Orleans region (Corn et al., 1999).

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 (Lafferty and Kuris, 1996). It also destroys commercial shellfish beds and preys on large numbers of native oysters and crabs (Lafferty and Kuris, 1996). The annual estimated economic impact of the green crab is US$ 44 million per year (Lafferty and Kuris, 1996). The pest green crab has also invaded ecosystems in Australia and South Africa (Lexis-Nexis, 1999).

An estimated 80,000 species of insects, 6000 species of spiders, and numerous other arthropod species exist in South Africa (Anon., 1989; South Africa, 1998). One of the most serious invaders is the Argentine ant (*Linepithema humile*), which is causing major problems by destroying native vegetation, including endangered plants (Macdonald et al., 1986). The same ant is also negatively affecting native ants and other beneficial species of arthropods (Kruger et al., 1989).

5.7. Mollusks

Eighty-eight species of mollusks have been introduced and become established in the US aquatic

ecosystems (OTA, 1993). Two of the most serious pests are the zebra mussel (*Dreissena polymorpha*) and Asian clam (*Corbicula fluminea*).

The European zebra mussel was first found in Lake St. Clair, having gained entrance via ballast water released in the Great Lakes by ships that traveled from Europe (Benson and Boydstun, 1995). The zebra mussel has spread into most of the aquatic ecosystems in eastern US and is expected to invade most freshwater habitats throughout the nation (Benson and Boydstun, 1995). Large mussel populations reduce food and oxygen for native fauna; mussel densities have been recorded as high as 700,000/m^2 (Griffiths et al., 1991). In addition, zebra mussels have been observed completely covering native mussels, clams, and snails, thereby further threatening the survival of native species (Benson and Boydstun, 1995; Keniry and Marsden, 1995). Zebra mussels also invade and clog water intake pipes and water filtration and electric generating plants; it is estimated that they will cause US$ 5 billion per year in damages and associated control costs by the year 2000 (Khalanski, 1997).

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 US$ 1 billion per year (Isom, 1986; OTA, 1993) (Table 3).

The introduced shipworm (*Teredo navalis*) in the San Francisco Bay has been causing serious damage to docks and ships since the early 1990s. Currently, damages are estimated to be about US$ 205 million per year (Cohen and Carlton, 1995) (Table 3).

6. Livestock pests

Microbes and other parasites were introduced when various species of livestock were brought into the six nations investigated. 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 US and become serious pests to US livestock (USAHA, 1984). A conservative estimate of the losses to US livestock from alien microbes and parasites is approximately US$ 3 billion per year (Drummond et al., 1981; Morgan, 1981) (Table 3).

In Australia, there are an estimated 44 alien diseases of animals that could infect livestock if they gained entrance (Meischke and Geering, 1985). In addition, three alien insect and mite species cause US$ 228 million per year damage to the wool industry alone (Slater et al., 1996) (Table 3).

In India, there are about 50 alien diseases of livestock and wildlife that are causing significant losses, including foot and mouth disease (Khera and Sharma, 1967). During 8 months in 1996, nearly 50,000 cases of foot and mouth disease were reported (Foot and Mouth Disease, 1998), with treatment costs of about US$ 17,000 per year (Singh, 1996).

Several serious alien livestock diseases in South Africa, including tuberculosis, brucellosis East Coast fever, anthrax, and rinderpest are infecting livestock, wildlife, and other animals. Estimates are that brucellosis alone is causing losses amounting to US$ 100 million per year (Coetzer et al., 1994) (Table 3).

In Brazil and other Latin American countries, imported bovine tuberculosis (TB) has become a serious threat to the development of the beef and dairy industry. These losses are reported to be approximately US$ 63 million per year (Cosivi et al., 1998)

7. Human diseases

7.1. AIDS, influenza, and syphilis

Perhaps the most notorious of all alien human diseases is the acquired immune deficiency syndrome (AIDS) that 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 infections and treatment costs in the US, UK, Australia, South Africa, India, and Brazil are shown in Table 4.

New influenza strains, originating in the Far East, quickly spread to the US and other nations. The influenza strains are reported to cause 5–6% of all deaths in 121 US cities (Kent et al., 1992). Costs of hospitalizations for a single outbreak of influenza, like type A, can exceed US$ 300 million per year (Chapman et al., 1992). In total, AIDS and influenza take the lives of more than 40,000 people each year in the US, and treatment costs for these diseases, plus syphilis, total

approximately US$ 6.5 billion each year (this does not include cost for other alien diseases) (Table 3).

New influenza strains in the UK are reported to cause from 3000 to 4000 deaths per year (Influenza, 1999). In total, AIDS and influenza take the lives of approximately 4000 people each year in the UK, and treatment costs total approximately US$ 1 billion per year, based on extrapolated data from the US (Pimentel et al., 2000) (Table 3).

New influenza strains in Australia are reported to cause about 210 deaths per year (Australian Institute of Health, 1997). In India, influenza cases total 3 million for 1984 (Government of India, 1984).

7.2. Other diseases

Several other non-indigenous diseases infect humans in Brazil, including malaria, cholera, yellow fever, and dengue fever (Alves et al., 1991; PAHO, 1998). The numbers of people infected include: cholera, 2167; malaria, 425,000 (PAHO, 1998); and dengue, 96,100 (Nascimento, 1998). If we assume that all these infected people are hospitalized and that the average cost per year per person for hospitalization from these diseases in Brazil is US$ 213 (Nascimento, 1998), then a minimum cost for these non-indigenous diseases is US$ 133 million per year. In addition, the Brazilian government plans on spending about US$ 1.4 billion per year to eradicate the *Aedes aegypti* mosquito, the vector of dengue and yellow fever (PAHO, 1998) (Table 3).

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

8. Control and future implications

The economic damages associated with the non-indigenous species invasions in the nations in the six continents total more than US$ 336 billion per year. The control costs in this total more than US$ 30 billion per year. Most of the control costs are associated with agricultural production (Pimentel, 1997).

Most attempts at eradication have failed once the invading species has become well established. In the US, 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 due to concerted efforts by the US Department of Agriculture and the Florida Department of Agriculture.

In Britain, efforts are being made to eradicate the introduced muskrat (*Ondatra zibethicus*) and coypus (*Myocaster coypus*) (Gosling and Baker, 1989). The populations have been significantly reduced, but the eradication effort has yet to succeed (Keymer et al., 1999).

The number of invading species worldwide have been increasing rapidly. For example, in the San Francisco Bay and Delta region, there has been a 10-fold increase in the number of invading species since 1900 (Cohen and Carlton, 1995). 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 a major effort to educate the public concerning the dangers of invading species.

9. Conclusions

More than 120,000 non-indigenous species of plants, animals, and microbes have invaded the US, UK, Australia, India, South Africa, and Brazil (Table 1). An estimated 20–30% 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 complex of ecological factors allows alien species to become abundant and 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. AIDS virus and humans); effective predators in new ecosystem (e.g. feral cats); artificial and/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. water hyacinth and zebra mussel).

The study documents that economic damages associated with non-indigenous species invasions in the six selected nations total more than US$ 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 forced to extinction. If monetary values could be assigned to species extinctions, losses in biodiversity, ecosystem services, and aesthetics, the costs of destructive non-indigenous species would undoubtedly be several times higher than the reported US$ 336 billion per year. Yet even this understated 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 US$ 240 per year. Assuming similar costs worldwide, then damages from invasive species would be more than US$ 1.4 trillion per year. Based on an estimated US$ 31 trillion in world GNP (PRB, 1998), then the US$ 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 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 in preventing further damage from invading alien species to natural and managed ecosystems worldwide, especially with current rapid human population growth and related activities. The US has taken a few steps in an effort to protect the environment from biological invaders. For example, President Clinton issued an Executive Order on February 2, 1999 creating an Interagency Invasive Species Council and allocating US$ 28 million to produce a plan within 18 months to mobilize the federal government defend against non-indigenous species invasions. In addition, Australia, South Africa, India, Brazil, and the UK all have specific programs in place to prevent the invasion 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 US and other nations will avoid billions of dollars in losses to agriculture, forestry, and other aspects of our managed and natural environment 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 (Sjoberg and Hokkanen, 1996). 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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