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chapter sixteen

Rodents and other vertebrate invaders in the United States

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16.1 *Introduction*

All living organisms slowly, but constantly, increase or decrease their populations, alter their distribution, compete among each other for resources, and sometimes emerge as new species or become extinct. Most such changes in the distribution and abundance of species are invisible or undetectable on short time horizons, but changes in the ecological status of vertebrate species are often evident and sometimes demanding of human attention.

When species move (or are moved) from their natural ranges to new areas and become established, they are variously termed "nonindigenous," "alien," "introduced," or "invasive"; the technical or legal definitions for these terms are still in developmental stages. In the United States, an invasive species was legally defined by executive order in 1999 as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health. (p. 6186)" This limiting definition has apparently worked for legal purposes but has made the technical literature somewhat confusing. Some authors have used "invasive" and various synonyms to focus on injurious species not native to the United States; others include indigenous species introduced to new ecosystems with the potential to cause harm,[1,2] and still others have focused on all nonindigenous species, including those presumed innocuous or desirable.[3]

The presence of many invasive species has long been tolerated; they are often accepted by the public as naturally occurring—so ubiquitous, they may have long-standing local common names. Examples of such species in the United States include Norway rats (*Rattus norvegicus*), house sparrows (*Passer domesticus*), pigeons (*Columba livia*), European starlings (*Sturnus vulgaris*), European carp (*Cyprinus carpio*), and brown trout (*Salmo trutta*). The problems caused by invasive vertebrates, particularly those that have been established for a few years or have become widespread, are typically managed on a case-by-case basis. These problems are pervasive and formidable, including environmental degradation in terrestrial and aquatic ecosystems; economic damage to agriculture, commodities, property, and infrastructure; transmission of human and livestock diseases or acting as disease reservoirs; competing with desirable or native species; threats to public safety; and overall reduction of quality of life for rural, suburban, and urban populations.[4] Pimentel[5] (Chapter 17, this book) has estimated that introduced vertebrate species cause $46.7 billion in damages and control costs each year. (All monetary values in this chapter are expressed in US dollars.)

As in other countries, most of the problem invasive vertebrates arrived in the United States through activities of man, some through direct, purposeful introduction, many by accidental transport, and some by natural range expansion.[6] Invasive species, whether arriving by accident or purposefully introduced, are often not recognized as potentially harmful until they have become well established and problems begin to be recognized. Even then, some invasive species are championed by individuals or groups as having beneficial or redeeming features, uncertain futures, or rights to exist (e.g., starlings, nutria, or coqui frogs), generating sometimes rancorous exchanges, and what might have been a straightforward eradication effort becomes an ongoing program of wildlife damage management.[7–9]

In the past two decades, increased attention worldwide has been placed on the problems engendered by invasive species across a wide range of concerns, and these concerns are growing.[10,11] In the United States, hardly a day passes that media attention is not somehow focused on an invasive species issue, variously involving legislatures, mayors, governors, state and federal agencies, the courts, concerned citizens, and advocacy groups on all sides. These concerns range across the real and growing problems of economic damage, ecosystem degradation, and competition with rare or desirable native species and the real or perceived threats of such impacts. A growing technical literature—papers, books, online resources, and the associated nontechnical, educational resources—has helped fuel both scholarly interest and public concern. Much of the technical material to date is largely descriptive and speculative, although there are increasing numbers of analytical studies and examples of successful eradications, suppressions, or management programs for particular invasive vertebrate problems.

The organizational structure for addressing invasive species problems in the United States is still evolving, with new organizational resources, particularly at the state level, appearing frequently. The National Invasive Species Council (NISC), established by a 1999 executive order,[1] is cochaired by the secretaries of agriculture, commerce, and interior to assure coordination of federal programs involving 13 federal departments and agencies. NISC (www.invasivespecies.gov), guided by an external advisory committee, has developed and maintained a National Invasive Species Management Plan and provides extensive resources to states, local jurisdictions, and the public, as well as providing international coordination.[12] A number of states have established parallel invasive species councils and state plans to address invasive species problems or those of particular groups. Hawaii, for example, established the Coordinating Group on Alien Pest Species (CGAPS), a public and private partnership, in 1995,[13] and the Hawaii Invasive Species Council (HISC) by legislation in 2003 both with a variety of specific functions, including public information, strategy development, and policy coordination among state and federal agencies. The result has been a proactive program for invasive species identification and control, including a well-advertised invasive species hotline[13] and, when necessary, legislatively mandated access to private lands for control operations.

Depending on the definitions used and methods of compilation, at least 81 invasive mammal species, 99 bird species, 69 reptile species, 11 amphibian species,[2] and 533 nonindigenous fish species[3] (Table 16.1) are established in parts of the United States (including Alaska and Hawaii, but excluding territories). In this chapter, we provide a brief overview of invasive species problems in the United States, summarize species accounts of some important species of concern, and discuss issues related to present and future management of these problems.

Table 16.1 Rodents and Other Invasive, Alien, or Nonindigenous Vertebrates Introduced in Parts of the United States

Mammals[a]	81
Rodents	18
Marsupials	2
Primates	6
Insectivores	2
Lagomorphs	6
Carnivores	14
Ungulates	33
Birds[a]	99
Waterfowl	5
Herons	1
Gallinaceous birds	25
Pigeons and doves	7
Parrots	20
Owls	1
Perching birds	40
Reptiles[a]	69
Turtles	6
Crocodilians	1
Lizards	56
Snakes	6

(Continued)

Table 16.1 Rodents and Other Invasive, Alien, or Nonindigenous Vertebrates Introduced in Parts of the United States (*Continued*)

Amphibians[a]	11
Frogs and toads	10
Salamanders	1
Fish[b]	533[b]
Lampreys	3
Sturgeons and paddlefish	4
Gars	4
Bowfin	1
Bonytongues, mooneyes, and featherfin knifefishes	4
Tarpons	1
Bonefishes	1
Freshwater eels	4
Anchovies and herrings	10
Milkfishes	1
Minnows, suckers, and loaches	156
Headstanders, trahiras, and characins	18
Catfishes	37
Pikes and mudminnows	10
Smelts	4
Trouts	30
Trout-perches, pirate perches, and cavefishes	3
Cods	1
Mullets	2
Rainbowfishes and silversides	7
Ricefishes and needlefishes	3
Rivulins, topminnows, live-bearers, splitfins, and pupfishes	54
Sticklebacks	4
Swamp eels	1
Sculpins	4
Snooks, basses, sunfishes, perches, roosterfishes, jacks, mojarras, grunts, drums, sea chubs, flagtails, cichlids, surfperches, wrasses, gobies, mackerels and tunas, butterfishes, gouramies, and snakeheads	158
Flounders	8

Note: These numbers, totaling 792, include species native to some parts of the country that have been introduced elsewhere outside their native ranges (mammals, birds, reptiles, and amphibians), and for fish, all established nonindigenous species.

[a] Estimated numbers of species for mammals, birds, reptiles, and amphibians summarized from Witmer et al.[2]

[b] Estimated numbers of fish species, hybrids, and unidentified forms summarized by order from Fuller et al.[3] Fuller et al.'s actual count from their database is 536 unique taxa.

16.2 *Assessing impacts of rodents and other vertebrate invaders*

The impacts and damage caused by vertebrate invaders in the United States have made this cluster of species a leading cause of environmental change and global biodiversity loss.[14–18] Invasions by nonindigenous species highlight the undeniable link between ecological and economic systems.[19,20] Ecological systems determine if the conditions are suitable for invasion and establishment of nonnative species; however, economic systems are affected by invasive species when the ecosystems are changed or diminished, when agricultural products are made unmarketable, or when public health and safety are compromised.[20–22] In general, the economic impacts of invasive species can be broken down into primary and secondary effects.

The primary negative economic effects most often caused by invasive species include disease transmission, predation, and/or destruction of environments.[23–25] Disease and predation cause mortality or morbidity in humans, companion animals, livestock, or wildlife,[26–28] while environmental destruction results from damaged ecosystems, crops, or property.[29–31] Valuation of the primary damage is usually accomplished by estimating the loss, market, and repair or restoration values associated with the affected resource. Loss values are often used in the case of death related to disease transmission, or predation to humans and companion animals, and in limited circumstances, wildlife. Market values are commonly used when monetizing the impact to livestock or crops.[17,20,22] In the case of property damage, repair costs are a typical method of valuation.[32,17] Finally, in the case of nonmarket ecosystems and wildlife, restoration values may be used to estimate the economic impact of damage to these resources.[33,34]

Primary effects can generate secondary effects due to interrelated economic factors that create linkages to established economic sectors.[25] For example, damage or destruction of an ecosystem is calculated by the number of acres damaged at the restoration price per acre. However, if the ecosystem damage also reduces tourism to the area, then the economic activity that would have been generated from tourist expenditures was also lost, representing a secondary impact.[25] Estimation of secondary effects usually requires the use of complex, computer-based input-output (I-O) simulation models. I-O modeling is an accepted methodology for estimating secondary impacts. This type of modeling attempts to quantify the impacts on output as a result of input changes in a regional economy based on the most current economic and demographic data available. An I-O model is developed by constructing a mathematical replica of a regional economy (city, county, state, etc.) that contains all the linkages between economic sectors (agricultural, manufacturing, and industrial) present in that economy. I-O models use the primary effect to generate the secondary effect, thereby calculating the resulting total effect on jobs and revenue in a specified regional economy.[35]

The challenge facing policy makers is to determine biologically effective and economically feasible methods of prevention, control, and damage mitigation of invasive species.[36] Accurate assessments of the economic impact of invasive species allow for the targeting of appropriate prevention and control methods.[37–39] The benefits and costs of all methods used to reduce the impacts of invasive species should be assessed to determine the most economically efficient techniques. Benefit–cost analysis is a common tool used by economists to evaluate programs and to determine the efficiency of management efforts; the monetary benefits and costs of program actions are identified and compared. A benefit–cost analysis is often used to value nonmarketed goods and services, such as environmental "goods."[40] The process of managing invasive species based on their environmental and economic impacts is an example. To estimate the values of such impacts, a number of measurement techniques have been developed.[41]

One accepted methodology to value nonmarket services is the damage-avoided method, which uses the value of resources protected as a measure of the benefits provided by a control program.[42] Benefits of any method to prevent, control, or mitigate the damage caused by invasive species are derived from the reduced burden associated with the impact of the species. Therefore, benefits are measured as cost savings resulting from diminished disease spread, predation, and/or environmental destruction. Costs are programmatic and derived from the labor and materials used to prevent, control, or mitigate invasive species damage. Total economic benefits of any control method are the summation of the primary and secondary effects "saved." The total economic benefits of the program can then be compared to total program costs to determine the economic efficiency. At least for the vertebrate invaders, economists have been slow to fully apply these tools to evaluate actual and potential impacts. Lack of such economic information is often cited at the political levels of government as a reason to tolerate invasion and establishment and to deal with problems that arise on an ad hoc basis.

16.3 *Accounts of some important vertebrate invaders*

Of the many invasive vertebrate species occurring in the United States, we provide species accounts of several that we view as particularly important because of economic losses, ecosystem impacts, or public interest.

16.3.1 *Norway rat (Rattus norvegicus)*

Introduced to North America about 1775 in trans-Atlantic shipping, the Norway rat[43,44] is now completely established in both rural and urban areas throughout the country, including Alaska and Hawaii. This species is one of the oldest and best-known invasive vertebrates in the United States and is responsible for a variety of types of damage to crops and stored commodities.[45,46] It spread rapidly and continuously across the country in shipped commodities, initially following wagon, riverboat, and rail routes. Areas with the least human traffic were the last to be reached.

The fur color of this rat is typically brown above and lighter brown gray below. The tail is sparsely haired and scaly, typically about the same length as the head and body. Its weight is about 500 g. One of the three common commensal rodent species on the North American continent, the Norway rat is closely tied to human settlements. Breeding may occur throughout the year. Populations expand rapidly when food, water, and habitat are available. Gestation is about 3 weeks, and animals reach sexual maturity about 3 weeks thereafter.[46]

In farm settings, damage to stored food and grains, damage to garden crops, and predation on eggs and baby chickens are common. Grain consumption and fecal contamination are common problems in commercial grain storage facilities.[45] Damage to roads, bridges, railroad track beds, and hydraulic structures may result from the burrowing activities and the associated soil loosening or flooding.[46] Structural damage in buildings results from gnawing and burrowing and may include damage to doors, window sills, and walls, as well as to pipes and wiring. Insulation may be damaged or removed in the course of nest building. In urban areas, Norway rat populations are commonly associated with poor sanitation or accumulation of trash and food refuse in inner-city areas, although outdoor feeding of pets and wildlife often support suburban populations as well. Norway rats serve as reservoirs of a number of diseases that may affect humans and domestic animals, most commonly salmonellosis, leptospirosis, and trichinosis.[44] In areas with high rat populations in close association with humans, rat bites may occur, particularly to babies and young children.

Davis[47] believed outdoor populations could be completely managed by environmental control and sanitation and demonstrated this repeatedly with experiments in Baltimore and New York City. However, Fall and Jackson[48] contended that the political and social impossibility of maintaining diligence by urban residents and sustained support by public and private sectors has allowed Norway rat problems to continue unabated. Numerous products are available commercially to property owners for Norway rat control, and extensive professional rodent control services are available through the structural pest control industry.[49]

16.3.2 *Roof rat* (Rattus rattus)

Roof rats, known also as black rats or ship rats, occur along port and shore areas in southeastern and western North America and throughout Hawaii and tropical Atlantic and Pacific Ocean islands. Although known most commonly as a commensal species closely tied to man, this species, particularly in warmer areas, readily establishes in landscape areas, including native forests in Hawaii and ocean islands. According to Brooks,[43] roof rats were well established in Virginia in the early 1600s. They were well established in North America's east coast areas by the 1800s. They occur sporadically in warmer inland areas but rarely persist. However, a recent infestation discovered in urban Phoenix, Arizona, raised concerns that the species could permanently establish in "islands" of suitable habitat and subsequently threaten crops and orchards.[50] In more temperate areas, they compete poorly with the larger and more aggressive Norway rats and occur mostly in port areas and generally indoors.[44]

The fur color is reddish brown, brown, or black, with the belly area being lighter or white. The tail is generally longer than the head and body. The weight of adults ranges from 150 to 250 g. As in Norway rats, breeding may occur throughout the year if resources are available, and the pattern of breeding is similar. Recently, a variant of *Rattus rattus*, the Asian house rat, has been separated taxonomically as *Rattus tanezumi*.[51] Animals of both species are generally similar in appearance; however, *Rattus tanezumi* appears more variable and has a somewhat shorter tail. A chief distinguishing feature is a differing number of chromosomes between the two species, but this is of course not evident without special study, and some authorities have not accepted the name change. *Rattus tanezumi* has recently been reported as a new invasive species in North America based on collections in California.[52]

Like the Norway rat, the roof rat invades homes and structures, causing damage and contamination of stored food and commodities. However, it readily adapts to field and forest habitats in tropical and semitropical areas causing damage to orchard, grain, and sugarcane crops. It preys on adult birds, nestlings, and eggs under some circumstances and is recognized worldwide as a likely cause of rare bird extinctions in many island areas, including Hawaii.[53–55]

This species is also a reservoir for a number of diseases of humans and animals but is most notorious for its role in bringing bubonic plague, the "Black Death," to fourteenth century Europe. The occurrence of bubonic plague in Hawaii during the period 1899–1958 was associated with this species,[56] as were the initial outbreaks in California in the early 1900s.[57]

Control methods and materials are the same or similar to those used for the Norway rat. However, this species has been a particular target of recent efforts, both in the United States and in many other countries, to eradicate them from islands where seabirds or other desirable species are threatened by rat predation.[58,59]

16.3.3 *Polynesian rat* (Rattus exulans)

The Polynesian rat (*Rattus exulans*) is a small tropical rat native to the Southeast Asia mainland, which spreads throughout islands in the Pacific in conjunction with human settlement of the region.[60] Although they do not occur on the United States mainland, they are well established on most tropical and semitropical islands (less than about 30° latitude) throughout the Pacific, including the Hawaiian Islands.[61] Polynesian rats are the smallest species (110–150 mm body length) in the genus *Rattus* and are slender (40–100 g), with relatively small feet and large ears. Like many rodent species, they are primarily nocturnal. Their fur is reddish brown on the dorsal surface and light gray on the belly area. Polynesian rats may breed throughout the year and have up to four litters annually with three to six young in each.[62] They are sexually mature at 2 months and may have a life expectancy of around 1 year.

Polynesian rats have adapted to a wide range of habitats from forests to grasslands to agricultural crops, such as sugarcane. They are good climbers but do not swim, so their dispersal to new islands is limited by human movement.[63,64,60] They are opportunistic omnivores, and their diet vary greatly by what is available and abundant by season and locale.[65–71] Predators of Polynesian rats include mongooses, cats, other larger rodents, and birds.[72] In addition, many Polynesian cultures consider rats to be a valuable food resource, and rodents may have been introduced into new areas intentionally for food.[64]

Polynesian rats are a significant agricultural pest throughout the Pacific region, and they damage a variety of crops, including rice, corn, macadamia nuts, sugarcane, coconut, cacao, pineapple, soybeans, and root crops.[73,69,70] Previous research documented the extensive effects of rat damage on sugarcane, but sugarcane production has largely been replaced by diversified agriculture in Hawaii.[55] Rat damage has now shifted to high-value seed crops (corn, soybean), and tropical fruits. Because Polynesian rats were spread through the Pacific Basin several thousand years ago, the impacts to the native flora and fauna are not readily apparent.[66,68,71,74] Polynesian rats are effective predators on seabirds, lizards, insects, and sensitive plant species that did not evolve with predation. Recent eradication efforts of Polynesian rats on islands have revealed these impacts as species recovery has occurred.[75]

A variety of methods have been employed to reduce the effects of Polynesian rats on agriculture and the environment. The primary successful methods have integrated rodenticides, alteration of cultural practices, and trapping.[70] Rodenticides have been effectively used to reduce agricultural damage, protect forest birds, and protect seabird colonies. Previous attempts to control rat damage biologically have been unsuccessful and deleterious to other species. The most frequently cited failure is the introduction of mongoose to Hawaii in 1883.[55]

16.3.4 *House mouse* (Mus musculus)

House mice are probably the most widespread mammalian species in the world next to humans. House mice originated in the grasslands of Central Asia and followed humans around the world. They are very good invaders and probably reached most parts of the world as stowaways on ships and cargo. House mice have remarkable abilities that have allowed them to be highly successful in many habitats around the world. Chief among these are their reproductive potential and their adaptability in different environments.

House mice are small, slender rodents with fur that is grayish brown above and gray to buff underneath. This small (about 20 g for adults) and highly prolific animal is a continuous breeder in many situations; a female can produce six to eight litters, each with four to seven young, per year. The young mature within about 3 weeks and soon become reproductively active. House mice are short lived (generally less than 1 year) and have high population turnover. In one study, 20 mice placed in an outdoor enclosure with abundant food, water, and cover became a population of 2000 in 8 months.[49]

House mice cause many types of damage.[76,77] A major concern is the consumption and contamination of stored foods; it has been estimated that substantial amounts of stored foods are lost each year in this manner. Mice also consume and contaminate large amounts of livestock feed at animal production facilities. Although mice generally live in proximity to humans,[49] sometimes feral populations occur. In these cases, the mice may damage many types of crops in the field, especially corn, cereal grains, and legumes. Australia has mouse "plagues" periodically resulting in enormous losses to stored crops and crops in the field.[78] In buildings, a mouse infestation can be a considerable nuisance because of the noise, odors, and droppings. More importantly, they damage insulation and wiring.[79] House fires have been caused by mice gnawing electrical wires; likewise, communication systems have been shut down for periods of time resulting in economic losses. Additionally, house mice are susceptible to a large number of disease agents and endoparasites. Consequently, they serve as reservoirs and vectors of disease transmission to humans, pets, and livestock.[80] Important among these diseases are leptospirosis, plague, salmonella, lymphocytic choriomeningitis, and toxoplasmosis. Finally, when introduced to islands, mice can cause significant damage to natural resources, including both flora and fauna. For example, on Gough Island, mice fed on nestling albatross chicks.[81]

A large number of methods and materials have been developed to help solve house mouse problems. In general, the use of multiple approaches and materials—integrated pest management—is more likely to reduce a mouse problem to a tolerable level. The tools available and their proper use have been extensively reviewed.[43,82,76,49]

16.3.5 *Nutria* (Myocastor coypus)

Nutria or coypu, semiaquatic rodents native to southern South America, are an invasive species having detrimental impacts mainly in the southern and eastern United States. Nutria were introduced into the United States in 1899 for fur farming and became established in several states.[83] Nutria dispersals resulted primarily from releases by fur farmers, escapes during hurricanes or rising floodwaters, or as translocations in an attempt to control nuisance aquatic vegetation. Some states, such as Louisiana, continue to recognize nutria as a beneficial natural resource for fur and food and manage populations for low densities—below presumed damage thresholds. In other situations, such as at the Blackwater National Wildlife Refuge in Chesapeake Bay, Maryland, where nutria have caused excessive marsh damage, government agencies have implemented an eradication strategy. Nutria and the damage they cause to crops, canals, and wetlands have been well described.[84,85]

Generally, nutria have dark brown fur and weigh about 5–9 kg. At first glance at a nutria swimming, they can be mistaken for a beaver or a muskrat, both rodents native to North America. Female nutria are polyestrous and are sexually mature at approximately 5 months old.[84] They are nonseasonal breeders capable of producing three to four litters a year with an average of four to five kits per litter. Nutria are voracious consumers of vegetation and are known to completely denude vegetation from areas where they feed before moving on. Their ease of mobility on land and in water makes them effective dispersers, posing significant challenges for resource managers.

The ravenous appetite of these herbivores can cause damage to agricultural crops and aquatic vegetation and can alter aquatic ecosystems. Crops damaged the most in the southeastern United States are rice and sugarcane, but other crops can be damaged as well: cereal grains, beets, peanuts, melons, and alfalfa.[84] In Louisiana, tens of thousands of acres of damaged marsh vegetation have been documented.[86] The areas damaged by nutria become permanent, open water ponds. Tidal and flooding impacts become more severe. The loss of marshland also removes habitat for native wildlife species such as waterfowl, wading birds, and muskrats. Finally, nutria burrowing habits can weaken irrigation structures and levees, and they are a host for some diseases.[84]

Nutria populations and damage have been controlled mainly by private hunters and trappers. When nutria fur prices declined in the 1980s, damage in many areas became a great concern. In Louisiana, a method was devised to manage nutria damage to supplement fur values with incentive payments to registered trappers and hunters of $4.00–$5.00 per nutria tail. Unlike classic bounty systems, the program is intensively managed to target specific areas for population reduction; in 2003–2004, 332,596 nutria tails were collected in designated harvest areas by 346 participants.[86] Rodenticides are rarely used for nutria control because of the concerns for hazards to nontarget animals and water quality. Research continues to develop new methods to control nutria populations, such as multiple-capture live traps[87] and improved attractants.[88]

16.3.6 *Gambian giant pouched rat* (Cricetomys gambianus)

Gambian giant pouched rats are native to a large area of central and southern Africa. They had become popular in the pet industry in some countries and became established on Grassy Key in the Florida Keys in 1999, following an escape or release by a pet breeder.[89] Despite a prolonged eradication effort, a free-ranging and breeding population remained on the island.[90] There is a concern that if this rodent reaches the mainland, there could be damage to the Florida fruit industry because Gambian rats are known to damage agricultural crops in Africa.[91] Imported Gambian rats may also pose risks as reservoirs of monkey pox and other diseases.[92] A climate-habitat modeling study suggested that their new range in North America could expand substantially were they to establish in the United States.[93]

Gambian rats are gray brown in color and can reach a considerable size—about 2.8 kg in weight and about 1 m long.[94] Females produce four young per litter. Because of their reproductive potential and their large size, they have been raised in captivity as a source of protein in Africa.[95] Since free-ranging Gambian rats are newcomers to North America, relatively little is known about their biology, habitat use, impacts, and interactions with native species or about the most effective means to capture or control these rodents. Hence, current efforts are concentrating on use of traditional live-trap capture methods and rodenticides in bait stations.[90] It will be important to develop additional tools to manage or eradicate this species and other rodent invaders from the United States.[96]

16.3.7 *Feral swine* (Sus scrofa)

Populations of feral swine have become established across the United States where their current range includes portions of at least 33 states.[97] Historical accounts of feral swine populations date to early European explorers, including Columbus, Cabot, Cortéz, and DeSoto.[98,99] These early populations, as well as the established and emerging populations, were founded from escaped domestic swine and through intentional releases of domestic swine, wild-caught feral hogs, and Eurasian wild boar;[99,100] today, feral swine populations are still comprised of these groups—now estimated at 4 million.[101]

Feral swine display high variability in body size, shape, and weight, as well as in pelage characteristics and coloration. Generally, their physical appearance is transitional between Eurasian wild boar, with a streamlined body and coarse dense hair, and domestic swine, with a round body and sparse hair.[101] While prevailing pelage color is black, other colors are common, including red, black and white spotted, brown, and roan.[99] Mean adult body weight for males and females from the southern United States range from 36 to 114 kg and from 34 to 92 kg, respectively.[101]

A major complicating factor in the management of feral swine populations is their exceptional reproductive potential. They are the most fecund, large, wild ungulate in North America.[102] Specifically, feral swine reach sexual maturity at a young age (5–10 months), have a large mean litter size (3.0–8.4), have the physiological capacity to breed year-round, and may produce two litters per year under favorable nutritional conditions.[101–103] These reproductive parameters suggest opportunity for management aimed at reducing birth rates to stabilize or reduce populations and related damage.[104]

Feral swine damage to property, agriculture, and natural resources often occurs as a result of their aggressive rooting, grubbing, plowing, and digging activities at and below the soil surface.[31] In sandy soils, feral swine may root to a depth of 1 m, causing extensive damage to crops, pastures, native plants, and farm equipment.[105] Rooting may also injure livestock and cause soil erosion.[101] Other sources of feral swine damage occur through wallowing, which may reduce water quality and disrupt sensitive wetland ecosystems,[29,30] destruction of livestock fencing,[105] and predation on young livestock and wildlife.[101] Feral swine are also present disease risks to both humans and livestock,[26] often carrying diseases, such as brucellosis, pseudorabies, and influenza.[27,28]

Methods that are available to control feral swine damage in the United States include exclusion fencing, trapping, and shooting.[31] Research efforts to develop immunocontraceptive vaccines and field-appropriate delivery systems,[106,107] coupled with improvements of existing control methodologies, are needed to formulate and implement comprehensive management programs for feral swine.

16.3.8 *Small Indian mongoose* (Herpestes javanicus)

The native range of the small Indian mongoose (*Herpestes javanicus*, synonymous with *H. auropunctatus*) extends from the Middle East through India, Pakistan, southern China, and parts of Indonesia.[108] During the late 1800s to early 1900s, mongooses were introduced with the hope of controlling rats and venomous snakes in sugarcane fields.[109,110] Thus, mongooses were introduced to many sugarcane-growing areas, including Puerto Rico, the Virgin Islands, and the Hawaiian Islands, in the hope of controlling rat damage.[111,112] Mongooses do eat rats, and early reports suggested that, while they were effective in reducing rat numbers, they were ineffective at exerting sufficient predatory impact to consistently reduce rodent damage.[113,114]

Mongooses are long (51–67 cm in length) and slender (300–900 g of weight) with short legs, small ears, a pointed nose, a bushy long tail, and short dark brown hair.[115] They are sexually dimorphic with males being larger than females. Mongooses have two to four offspring in a single litter each year but are capable of breeding year-round depending on food supply.[116] Further, where mongooses have been introduced, they have few predators or competitors to restrict their populations. Mongooses are found in a variety of habitats from tropical forests to open dry grasslands, marshes, and coastal sites, as long as adequate retreat sites are available. Mongooses are opportunistic omnivores and eat mammals, birds, reptiles, insects, and significant amount of plant material.[113,114,116] Home ranges are variable and may be small; however, the animals may move great distances to utilize unique or anthropogenic food sources.

Mongooses may have major economic impacts on local economies, agriculture, and natural resources, with damage estimates exceeding $50 million annually to Hawaii and Puerto Rico.[117] In addition, poultry, egg production, and game bird populations may be impacted unless significant efforts are made to exclude or control mongoose populations. In some areas, they may be reservoirs for several diseases threatening humans or livestock, including rabies and leptospirosis.[112,117,118] Mongooses are effective predators of ground-nesting birds and have been implicated in the extirpation of several species.[56,109,112,119,120] They have also had negative impacts on frogs, lizards, snakes, turtles, and small-mammal populations.[110,121–124]

Most mongoose control efforts have primarily related to attempts to protect ground-nesting birds or poultry operations using traps and toxicant baits.[125,126] Local control of mongoose populations has been most effective when kill traps, live traps, and toxicants are combined. Mongooses are very susceptible to toxicants including anticoagulant rodenticides. Large-scale eradication efforts and removal of incipient populations have proved to be difficult because of the availability of alternative foods and large foraging areas.[110,112,126]

16.3.9 *Rock pigeon* (Columba livia)

The rock pigeon, also known as the feral pigeon or rock dove, is a common sight in urban areas throughout the United States. Its native range extends from Britain to India, including northern Africa.[127] Although the species is most commonly associated with cities and towns, feral populations also inhabit rural and undeveloped areas throughout the range. Feral rock pigeons are highly variable in appearance due to frequent interbreeding with domestic forms. Plumage of the wild form is generally blue-gray with a green and purple iridescence on the neck feathers. The wings have two black bars; the rump is white.[128]

The rock pigeon is likely the nonnative bird species with the longest tenure in the United States. It apparently arrived with early European colonists, along with poultry and livestock, in the early 1600s.[127,129] There have been many subsequent introductions, and the species has thrived in concert with human development and expansion. These pigeons now occur in all 50 states including Hawaii where it was introduced in 1796.[127]

The species is characterized by early sexual maturity; pigeons often breed before they are 1 year old.[128] In some locales, shortages of suitable nest sites might prevent all sexually mature birds from breeding. Depending on latitude, up to five clutches can be produced annually; clutch size is two. The average lifespan is about 2.5 years.[128]

Damage attributed to rock pigeons in the United States has been estimated to exceed $1 billion annually.[18] Negative impacts of pigeons include defacement and degradation of property and consumption or despoilment of grain and other food intended for livestock and humans. Pigeons are also associated with harboring or transmitting over 40 zoonotic diseases.[130] On the plus side, pigeons provide an important food source for urban-nesting peregrine falcons that were introduced to cities with high-rise buildings to help preserve threatened populations.[131] Furthermore, many people enjoy feeding pigeons in parks and urban centers. This recreational activity brings pleasure but also frustrates efforts to manage urban pigeon populations effectively. Methods for reducing pigeon populations and for addressing problems caused by pigeons are numerous and include exclusion, chemical repellents, toxicants, auditory and visual scare devices, trapping, and contraception.[132,133]

16.3.10 *House sparrow* (Passer domesticus)

According to Dawson,[134] the introduction of the English sparrow was "Without question the most deplorable event in the history of American ornithology . . . (p. 40)" The history of the house sparrow (often known as the English sparrow) in the United States dates from the early 1850s when at least 16 birds were released in New York City.[135] That event was followed by numerous subsequent releases, and the species eventually became established throughout the United States, including Alaska and Hawaii[127,136] The house sparrow is not migratory in the United States.

House sparrows have an extensive native range, and they are resident from the British Isles, Scandinavia, Russia, and Siberia south to northern Africa, Arabia, India, and Burma.[136] Introduced populations thrive in many other parts of the world.[127] Adult sparrows are about 16 cm long with bodyweights of about 28 g. Females and juveniles are a nondescript gray-brown in color. Males have a distinctive gray crown with a chestnut border, white cheek, and black throat and upper breast.[136] House sparrows have up to four clutches annually with four to six eggs per clutch.[137] Their diet is mostly grain and weed seeds, supplemented by insects and other invertebrates during the breeding season.[138] Bird seed (from feeders) in urban birds and commercial grains in rural birds were the principal food items recorded in one comparative study.[139] House sparrows readily consume livestock and poultry feed, and their droppings contaminate stored grain and create unsanitary conditions.

The house sparrow is primarily a commensal species in the United States, thriving in association with human activity and development. They frequent rural habitats around farms and dairies, as well as urban centers, where individual sparrows sometimes take residence inside large commercial buildings or stores or in airport terminals. They select nest sites in nooks and crevices on buildings and other structures, and they will readily usurp nest boxes intended for native hole-nesting species.[140] Very detailed guidance on how to protect bluebirds and other native species from house sparrows are available at http://www.sialis.org/hosp.htm.

House sparrows are associated with the transmission of at least 25 diseases potentially affecting humans or livestock.[130] Furthermore, they can harbor numerous types of ectoparasites. Because house sparrows often build their nests on buildings occupied by people, some of the parasites (e.g., the bedbug *Cimex lectularius*) can prove injurious to humans.[130] Management of problems caused by house sparrows is best accomplished using a combination of methods, including trapping, nest destruction, and exclusion. Many trap designs and other products are available.[141]

In the United States, the house sparrow population is in the midst of a sustained downward trend that reflects the trend throughout North America.[142] The reasons for this decline are unclear but might be related to the increasing conversion of American agriculture to large monoculture operations that renders formerly ideal rural farm habitats unsuitable.

16.3.11 *European starling* (Sturnus vulgaris)

The starling is a very successful invader worldwide and is on the list of 100 of the World's Worst Invasive Alien Species (http://www.issg.org/database/species/search.asp?st=100ss). In the United States, the starling became established following releases of 60 birds in 1890 and 40 more in 1891 in New York's Central Park.[127] During the next 50 years, the species spread across the country reaching the West Coast in the 1940s.[143] Currently, starlings are year-round residents from southern Alaska and Canada to northern Mexico with an estimated population of over 200 million.[144]

The starling is a stocky, compact bird, averaging 80–90 g body weight. It has a glossy black plumage, short, squared tail, pointed wings, and long bill. The plumage has a green/purple iridescence. The sexes look alike. During the nonbreeding season, the head and body feathers have whitish tips which give the bird an overall spotted look. These spots wear off during the winter and are virtually gone by the next breeding season.[144]

Under favorable conditions, starlings can produce two clutches per year, with—four to six eggs per clutch. Starlings nest in natural and man-made cavities. Although aggressive and territorial in the breeding season, the starling is highly gregarious during the nonbreeding season. Starlings form large feeding flocks and share huge multispecies roosts in the winter. Both migratory and nonmigratory individuals can occur in the same population.[143]

The starling is responsible for an estimated $800 million of agricultural damage in the United States annually.[18] This includes depredations to fruit (cherries, blueberries, grapes) and grain crops, as well as feed consumption and fecal contamination at livestock feedlots and dairies, which may harbor huge numbers of birds. Starlings have been associated with transmission of at least 25 diseases, including toxoplasmosis, chlamydiosis, and salmonellosis.[130]

Beyond agricultural impacts, starling flocks cause numerous nuisance and damage problems through defecations on buildings, vehicles, and public spaces. Starlings are one of the most numerous bird species found in electric substations.[145] Because of their solid build and flocking tendency, starlings are a major risk to aircraft safety. According to the U.S. Federal Aviation Administration, there have been over 2000 reported collisions between starlings and civil aircraft since 1990.[146] Furthermore, starlings have impacted numerous native species through harassment and competition for cavity nest sites.[144] After many years of expansion, the trend of the European starling population has in recent years exhibited a broad decline throughout the United States.[142] The reason for this decline is unknown.

16.3.12 Monk parakeet (Myiopsitta monachus)

The monk parakeet (also known as the Quaker parrot) is a medium-sized parrot, approximately 30 cm long, weighing 100–120 g. These gregarious parrots have bright green backs and tails, and flight feathers with bluish cast. In contrast, their faces, throats, and breasts are pale gray. The sexes appear identical.

Their native range includes temperate and subtropical lowland regions of Argentina, Uruguay, Paraguay, and Brazil where they inhabit croplands, savannahs, and woodlots, including nonnative *Eucalyptus* stands planted as windbreaks. Monk parakeets have been introduced in many countries including the United States, Canada, Israel, Bahamas, Belgium, Italy, England, and Spain.

Thousands of monk parakeets were imported to the United States in the 1960s for the pet trade. The first free-flying birds were observed in New York in 1967[147] and Florida in 1969.[148] Since then, monk parakeet populations have been documented in over a dozen states.[149] The largest populations occur in south and southwest Florida, but thriving populations also exist in Texas, Connecticut, New York City, and Chicago among others. Unlike their selection of habitats in their native range, monk parakeets in the United States occupy habitats in urban and suburban areas. While the monk parakeet population in the United States exhibited exponential growth for many years, since 2005 the population has been steadily declining.

Monk parakeets have a variable diet comprised of seeds, fruits, berries, nuts, flowers, and leaf buds. In many locations, they obtain much of their food from backyard bird feeders. In South America, the species is considered a major crop pest,[149] but only isolated crop damage has been reported in the United States.[150]

Monk parakeets are unique among psittacines in that they do not nest in cavities but instead construct a large nest of sticks and branches. In the United States, they nest in trees and on radio towers, light poles, and electrical utility structures. The nest structure is maintained year-round, and as the structure is enlarged, other pairs of birds add nest chambers so that eventually a single, large structure can hold several nesting pairs.[151]

In the United States, their greatest economic impact is from nest construction on electric substations, transmission towers, and distribution poles. When nest materials get wet, the nests can cause short circuits, disrupt power, and damage sensitive equipment. No reliable, effective measures are available to prevent parakeet nesting on electric utility structures.[152] Although only temporarily effective, removal of nests from sensitive utility facilities is the most common method employed to prevent problems. In south Florida, during a recent 5-year period, costs associated with nest removal were estimated at $1.3–$4.7 million.[153] Long-term management options include the use of contraceptives to lower parakeet population levels.[153,154]

16.3.13 *Brown tree snake* (Boiga irregularis)

Brown tree snakes (*Boiga irregularis*), native to Australia, New Guinea and adjacent archipelagos, and the Solomon Islands, were probably introduced to the island of Guam as stowaways from Manus in the Admiralty Islands, north of New Guinea, shortly after World War II.[155,156] In 30 years, snakes spread throughout the island of Guam and attained extremely high population densities of 50–100 snakes per hectare in some areas.[155] Brown tree snakes are slender colubrid snakes, light brown in color, mildly venomous, and typically less than 2 m in length. The snakes are nocturnal and primarily arboreal, although they may be found on the ground.

As snakes spread across the island, their diverse food habits and the high population densities caused extirpation or drastic population reductions of Guam's resident bird species and native lizards and negative impacts to other wildlife.[156–160] Snakes have also had a significant impact on Guam's economy, agriculture, and human safety.[25] Because brown tree snakes are rear-fanged snakes and must chew to inject venom, their bites are unlikely to be fatal to adults. However, infants and small children (less than 10 years) are at risk for fatal bites, and bites to children and adults may exceed 170 bites per year.[25] Brown tree snakes are arboreal and use the tree canopies to move through landscapes; utility poles and wires provide ideal travel corridors. Snakes may ground electric systems when they move from grounded utility poles to electrified wires, thus producing power outages. In Guam, these power outages happen about every 2–9 days and cause millions of dollars in damage annually.[25,161] Additional effects of the high snake populations include loss of pets to predation, poultry industry losses, and concerns with the potential for diminished tourism.[25,162]

Brown tree snake management is focused on reducing the risk of snakes leaving the island and becoming established in other areas and on reducing their impacts to Guam. The risk of importation to Hawaii, with its many endangered species, and its thriving tourism industry is of particular concern. A combination of live trapping, hand capture from spotlight searches of fence lines, barriers, and the use of trained detector dogs are the primary interdiction methods to restrict snakes from aircraft and cargo leaving the island.[163–165] The trapping and spotlight searches are used to reduce the number of snakes in active transportation areas, then trained detector dogs are employed to search all cargoes leaving the island. This multitiered program has thus far been effective in preventing snakes from establishing in other Pacific island areas. To reduce the impacts to Guam, methods are being developed to deliver snake toxicants over large areas.[166] Other potential methods to control snakes include the use of repellents, fumigants, reproductive inhibition, and barriers, but these have yet to be deployed over large areas for population suppression or eradication.[163,167]

16.3.14 *Burmese python* (Python molurus bivittatus)

The Burmese python is a large invasive constrictor that has been entrenched in southernmost Florida for over a quarter-century.[168] The species' invasion pathway in south Florida has been attributed to illegal pet releases, although the highly destructive Hurricane Andrew in 1992 may also have released snakes from damaged captive breeding and holding facilities.[169,170] The origins of Burmese pythons entering the pet trade, and hence arriving in Florida, came from a portion of its native range, primarily Thailand near Bangkok (initially) and subsequently from Vietnam near Ho Chi Minh City after 1994.[171] Recent genetic testing of Burmese pythons showed little genetic differentiation among specimens captured in south Florida, but these specimens are genetically distinct from Vietnamese specimens; comparisons to Thai pythons were not conducted.[172] One possible consequence of minimal genetic variation among Florida pythons may be reduced ecological flexibility to adapt to significant changes in climatic conditions.

Burmese pythons are popular in the pet trade because of their relative docility and attractive coloration, with black-bordered dark brown blotches on a lighter background. The species is among the world's largest snakes, growing to over 7 m and weighing 90 kg,[173] with the largest Florida specimen reaching about 5 m. Burmese pythons are generalist feeders, consuming primarily mammals and birds but also reptiles, amphibians, and fish.[174] Their ecological impacts in south Florida continue to be identified, with documented predation on many native species, including endangered species.[174,175]

Burmese pythons are primarily a tropical lowland species strongly associated with water, with the vast majority of their native habitat below 200 m in altitude,[176,177] making south Florida an ideal locale for their establishment. Burmese python observations in south Florida have been expanding in recent years, including southward to the nearest island, Key Largo.[170,175] The potential range for python population expansion in the United States has been the subject of considerable controversy.[171,17,178] Projections of potential range expansions have used means such as climate matching with information from within the native range of the Burmese python and the closely related Indian python (*Python molurus molurus*),[178] and ecological niche modeling using the Burmese python's native range information.[179] Few empirical physiological and behavioral data are available on the Burmese python response to cooler mean temperatures and prolonged cold spells in the United States, but the available information seems to place doubt on whether this tropical species could establish sustained breeding populations beyond the warm climate and wetland habitats of south Florida.[180]

Smith et al.[181] have attempted analysis of the economic benefits for addressing the problem of snake depredations. Development of control tools and strategies for Burmese pythons is in its infancy and will likely follow similar conceptual approaches used for brown tree snakes (*Boiga irregularis*) on Guam.[163] Research has been initiated by several state and federal agencies and university scientists on technologies and strategies for controlling this invasive predator, including capture mechanisms, detection methods, reproductive vulnerabilities, baits and chemical cues, and toxicants.[170,182,183]

16.3.15 *Coqui frog* (Eleutherodactylus coqui)

The terrestrial tree frog *Eleutherodactylus coqui* was introduced to Hawaii from Puerto Rico via the horticultural trade in the late 1980s.[184] Since their introduction, coqui frogs have spread to six of the eight main Hawaiian Islands and are most widespread on the islands of Hawaii and Maui. Coqui frog populations occur in wet lowland forests and cover about 16,000 ha on the island of Hawaii and several hundred hectares on Maui. Due to extensive control efforts, only a few populations remain on Kauai, and incipient populations have been removed from Oahu, Lanai, and Molokai. Small populations and individual frogs have been reported from Florida, California, Guam, and the Virgin Islands.[185]

The most distinguishing feature of the coqui frog is the loud, two-note "ko-kee" mating call of the male—nearly 80 dB at 5 m. Coqui frogs are small tree frogs (30–50 mm in length) that vary in size across their native range, with females slightly larger than males.[185] Although numerous color and pattern variations have been described, frogs are typically gray to brown and may have a lighter colored stripe (or stripes) on the dorsal surface.[186] Coqui frogs are not dependent on standing water for reproduction; small froglets hatch directly from eggs.[187] These frogs reproduce up to four times a year and average 28 eggs per clutch.[188]

In Hawaii, coqui frog populations may exceed 50,000 frogs per hectare,[189,190] and because of these high densities, frogs may reduce native invertebrate populations, compete with native birds, alter food webs, and increase the nutrient cycling.[190,191,192] The loud frog calls have made people reluctant to purchase property or products infested with frogs, thus affecting agriculture, real estate, and the local economy.[191,193,194] Additionally, new quarantine and treatment procedures for minimizing the spread of frogs have increased the costs to the floriculture industry. Although the chytrid fungus *Batrachochytrium dendrobatidis* has been implicated in worldwide amphibian declines, chytrid has little effect on coquis, and because they are carriers, they could spread the organism, thus contraindicating its use as a biological control agent.[195,196]

A wide variety of techniques have been investigated to control frogs, but chemical control has been the most effective and safest option for large populations. A 16% solution of citric acid, a common food additive, classified as a "minimal-risk pesticide" exempt from federal registration requirements, has been approved by the Hawaii Department of Agriculture and is effective in controlling frog populations with minimal nontarget effects.[197] Other chemical options have been effective, but no other chemical control is currently registered for frog control. In addition to chemical control, hot-water treatments have been an effective means to kill frogs in plant shipments.[198] Mechanical controls, including traps and hand capture, and vegetation management have been effective on smaller-scale infestations.

16.3.16 *Sea lamprey* (Petromyzon marinus)

The sea lamprey (*Petromyzon marinus*) is a primitive boneless, jawless fish with a cartilaginous skeleton. They are native to the Atlantic Ocean, spawning in freshwater rivers,[3] but have long been a textbook example of a vertebrate invader causing great economic damage to commercial and sport fisheries by their establishment in the Great Lakes.[199] Adults are about 30–50 cm long and weigh about 225–370 g. They are grayish blue-black with metallic violet on the sides and silver-white coloration on the undersides. The body of the lamprey has smooth, scaleless skin with two dorsal fins (but no paired fins), no lateral line, no vertebrae, and no swim bladder.[200,201] Lampreys have a sucking disk mouth with sharp teeth surrounding a file-like tongue. They attach to fish and rasp into the soft tissues, feeding on body fluids, usually with lethal effects.

Sea lampreys were first observed in Lake Ontario in the 1830s, having entered through locks and canals. Niagara Falls served as a natural barrier, blocking lamprey entrance into the upper lakes until modifications to the Welland Canal in 1919 allowed the species to invade and spread through the rest of the Great Lakes system, where they were fully established by 1938. Establishment of sea lampreys was a principal factor in the collapse of the lake trout, whitefish, and chub populations during the 1940s and 1950s. Canadian and United States fisheries had harvested about £15 million of lake trout each year from the upper lakes, but by the 1960s, the harvest had fallen to £300,000.[200]

An ongoing integrated management program has resulted in a 90% reduction of sea lamprey populations.[201] Lampricides, aquatic pesticides selective for sea lamprey larvae, developed in the 1950s, are applied to some of the streams and tributaries where lamprey spawn every few years.[202] Other control methods include barriers constructed on streams to selectively block the migration of spawning lamprey while allowing other fish to pass with minimal disruption—including electric barriers that repel lampreys, velocity barriers that target lampreys' poor swimming ability, and adjustable-crest barriers that are inflated during the spawning run and deflated the rest of the year. Trapping of lampreys moving to spawning areas is also used, often in conjunction with barriers. In some areas, particularly the St. Mary's River, trapped male lampreys are sterilized and released into streams to compete with normal males.[201] Extensive technical resources and bibliographies, including many of the early unpublished reports, are maintained by the Great Lakes Fishery Commission (http://www.glfc.org).

16.3.17 *European and Asian carp* (Cyprinidae)

European carp (*Cyprinus carpio*) were introduced to the United States at some time during the middle to late 1800s (early date records for identification apparently conflict), originally as a food fish that was stocked throughout the country by the U.S. Fish Commission.[3] The species is now widely distributed in inland waters in at least 45 states, including Hawaii, and causes substantial damage to wetlands and aquatic ecosystems by habitat destruction and increased turbidity, competition for food with more desirable native species, and predation.[3] Few control efforts have been successful and, although the species is now often shunned as a food fish because of its association with polluted waters, it is sometimes managed by sport fishing and bow hunting.

More recently, concern has focused on the introduction of Asian cyprinids, including the grass carp (*Ctenopharyngogon idella*), the black carp (*Mylopharyngodon piceus*), the bighead carp (*Hypophthalmichthys nobilis*), and the silver carp (*Hypophthalmichthys molitrix*). These species were introduced to the United States in the 1960s and 1970s, originally for use in aquaculture, and escaped into lakes and rivers during flooding or through intentional movement of stocks. The latter two species, first found in native waters in the 1980s, are well established in the Mississippi River drainages.[203] These species grow rapidly and may weigh up to about 45 kg as adults. Scientists have speculated they are the most abundant large fish in the lower Mississippi River and describe impacts to include hazards to boaters and water skiers from the large, jumping fish, as well as direct competition with native fish for food and space, and predation on larva of native forms.[204]

These two carp species are of specific current concern because of potential dispersal from the Mississippi River Basin into the Great Lakes. Establishment in the Great Lakes would disrupt food chains supporting native fish and pose significant threats to Great Lakes ecosystems.[205] Since both commercial fishing and sport fishing, as well as tourism, boating, and water sports, are major facets of the shoreline and lake island economies, public concern and political action have increased as the carp issues became more widely known. The problem of Asian carp management has been described in detail, and the variety of research needs and potential control methods has been outlined.[206] Control and prevention efforts, including use of netting, the fish toxicant rotenone, and construction of an electric barrier in the Chicago Sanitary and Ship Canal, have appeared to protect the Great Lakes from invasion for an extended period. More recently, continuing concerns related to new detection methods brought the issue of closing navigation locks as a further means of keeping fish from entering the Great Lakes ecosystem from the Mississippi River Basin to the U.S. Supreme Court, which denied the request.[207] Containing the spread of Asian carp continues to be an important environmental issue.

16.4 Offshore threats

While the rodents and other vertebrate invaders already established in country are a serious concern, the potential for continuing invasions in the future must also be considered. These threats deserve careful analysis because on one hand, managers and decision makers should be alerted to potential primary (the invasive species themselves) and secondary impacts (including the associated diseases and parasites[208]) of vertebrate invasions, while on the other hand, the scientific and political disagreements this may entail are confusing to everyone and may sometimes be counterproductive, particularly if alarmist approaches make their way into mass media.[171,178,179,193]

The future threats of potential rodent invasions are illustrative. The source populations of the three species of commensal rodents (*Rattus norvegicus*, *Rattus rattus*, and *Mus musculus*) established throughout the United States were likely established in the European ports with substantial ship traffic bound for the New World colonies. Spread of these species throughout the country was fostered by their close association with human settlements and their propensity to infest commodity shipments and household goods moving by wagon, ship, riverboat, and railroad. They now occupy a number of sylvatic and agrarian habitats on the fringes of settlements, as well as the urban and suburban areas where they are ubiquitous. They have also established on a number of islands where they may occupy a wider range of habitats and a show wider range of food selection, causing myriad problems in these fragile ecosystems, particularly impacts on endangered species.

A number of other rodent species, most commonly recognized as agricultural pests in different parts of the world, sometimes occur as local commensals and may be found in port or shipping areas. These include *Apodemus agrarius* in East Asia, *Apodemus sylvaticus* in Europe,[209] *Bandicota bengalensis* and a number of smaller species in South Asia,[210,211] *Rattus exulans* in Hawaii and Pacific islands (where it is known as the Polynesian rat) and Southeast Asia (where it is known variously as the little Burmese or little Asian house rat),[211] *Rattus tanezumi* (a newly redesignated Asian variant of *Rattus rattus*)[51] that occurs in temperate and tropical areas of Asia and has already reached North America,[52] *Mastomys* [*Praomys*] *natalensis*,[211] and *Arvicanthis niloticus* in east and west Africa.[212] With the globalization of trade, containerized shipping, and the emphasis on increasing the range of trading partners, the probability of accidental transport of such species to the United States has clearly increased. The pet trade, which through accidental escapes or intentional releases of imported exotic animals, has been another principal route of the invasion and establishment of potentially injurious animals into the United States.[213] Increased efforts to identify and predict potential vertebrate invaders and to catalog potential primary and secondary problems, as well as to develop information on ecology and effective control methods in native ranges, should prove valuable, if not essential, in the future.[21,214]

Although the introduction, and at least local establishment, of some invasive species has happened in relatively short time spans (e.g., Asian carp, brown tree snakes, nutria, Gambian giant pouched rats), other species took decades to establish and move throughout the country (e.g., Norway rats, rock pigeons, house sparrows). The difficulties of rapid detections of invasions (or other events that occur in low frequencies) are well known. This may be a particular problem with invasive rodent species that are mostly nocturnal and similar in appearance, especially without specimens in hand.

Detection of invader propagules that may lead to incipient invasive populations holds the same challenges as monitoring populations for management or eradication. The detection of rare events (including the occurrence of animals in low numbers) can obviously be enhanced by increased sampling effort. Sampling effort is maximized within available resources if the sampling methods and observations are easily implemented and understood. Furthermore, quantification of animal population status can be greatly improved by applying detection methods that take advantage of behavioral characteristics, which increase the probability of observation, and by using measuring methods that are continuous rather than binary.[215–219] Public involvement in early detection efforts can be an important component, and a number of state and local programs have begun proactive efforts of public education using print and broadcast media, posters and displays, and in some cases establishing telephone "hotlines." Hawley[220] described a particularly well-organized and comprehensive public involvement program in Saipan, using modern marketing tactics to attempt to prevent importation and establishment of brown tree snakes.

16.5 Discussion

Worldwide, rodents and other invasive vertebrates have had devastating effects on the human enterprise and quality of life. Along with habitat loss and human activity, vertebrate invaders have been a principal cause of extinctions and continuing risks to endangered and threatened species in many areas. Infectious diseases and parasites carried with these invaders have amplified their direct effects on humans, domestic animals, wildlife, and the environment. The United States has been no exception to these effects.

Awareness of invasive species problems has greatly increased during the past several decades from the time when Norway rats, pigeons, starlings, and sea lampreys were the major vertebrate invaders that biologists studied and the public encountered. The prospects of needing to address the arrival and establishment of new vertebrate invaders appear almost certain. A central problem for biologists (and for politicians and the public) is to avoid thinking and planning only for the short term when analyzing the risks of vertebrate invasions and to consider longer time-horizons, best said as "ecological time,"[221] that involve time scales of decades or generations rather than years.

The questions of eradication versus management, particularly of new invaders, also require careful consideration in long-term planning since these actions may require substantially different strategies. Eradication is clearly feasible for founder populations and on small scales, based on the recent successes with island populations of rodents, carnivores, and ungulates. But the rapid response, persistent sustained action, and continuing surveillance required for successful eradication present both ecological and political challenges, and delays make any effort progressively more complex, expensive, and difficult to sustain. At some point, any eradication effort if not demonstrably successful in the short term—particularly if the invader, the invaded environment, or the impacts do not attract public concern—can easily slip into the case-by-case management mode typical of how vertebrate–human–wildlife conflicts are handled. In the long run (ecological time), continued faunal mixing,[222] with range changes, the loss of some species, and the addition of new nonindigenous species, including some that are injurious, seems inevitable. Many of these changes will happen slowly, and many will be undetected despite our best efforts. The social effect of the shifting baseline syndrome (in which each generation bases its ecological expectations on its own life experience rather than on historical patterns)[223,224] works against attempts to fend off these changes, making the case-by-case strategy of managing the specific problems caused by invasive species the most likely way to successfully mitigate impacts. Obtaining the ecological information and developing the range of vertebrate management tactics needed to accomplish this effectively are among the national challenges for the future.

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