Terrestrial Animals as Invasive Species and as Species at Risk From Invasions

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Abstract

Including terrestrial animal species in the invasive species strategy plan is an important step in invasive species management. Invasions by nonindigenous species threaten nearly 50 percent of imperiled native species in the United States and are the Nation's second leading cause of species endangerment. Invasion and conversion of native habitats by exotic species can have detrimental effects on animal species by reducing habitat quality through changes in habitat structure, shelter, food availability, and community interactions. Managers need information about invasive animals and native animal responses to invasions to prepare management plans. Regulatory laws such as the Endangered Species Act require that potential effects on animal populations be evaluated before taking action to alter or restore habitats. "Injurious" invasive animal species must also be regulated under the Lacey Act.

The Forest Service is well positioned to address problems caused by invasive animals and mitigate effects of invasive exotic species on native animals. National forests and grasslands provide diverse habitats for numerous wildlife species. The Forest Service has scientists, ongoing studies, networks, partnerships and experimental forests and ranges focused on understanding problems linking animal species, invaders, and habitat changes.

Many of our customers are currently based in rural areas, but customer demand can be expected to shift over the next 50 years to urban communities as rural areas become urbanized. Our range of customers will expand worldwide as invasive species problems become increasingly global. Preventing global homogenization, or the ecological replacement of native species with widespread exotics, will require global communication. It is imperative that the Forest Service take an active international role in communicating solutions about this topic to a global community.

Key future issues for terrestrial animals include the following:

- Protecting wildlife from endangerment by invasions.
- Rehabilitating invaded riparian habitats and conserving riparian-obligate species.
- Managing damage to wildlife habitats from introduced insect species.
- Restoring and rehabilitating invaded wildlife habitats prone to fire outbreaks.
- Conserving animal species affected by habitat conversion and fragmentation.
- Managing wildlife habitats in relation to invasions propagated by climate change.
- Managing urban-wildland areas invaded by high numbers of nonnative species.
- Mitigating and managing the effects of nonnative diseases and viruses spread by animals.
- Detecting and eradicating invasive species in areas of high wildlife diversity.
- Understanding patterns and movements of invasive organisms across landscapes.

The top five priorities for terrestrial animals are as follows:

1. Develop knowledge and tools to manage and mitigate the effects of invasions facilitated by globalization, urbanization, and climate change on distributions and abundances of native animal species.
2. Develop knowledge and tools to improve the effectiveness of invasive species management and minimize management side effects.

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3. Develop knowledge and tools for managing invaded woodland, desert, steppe, and grassland ecosystems to conserve native species.
4. Develop knowledge and tools to manage and rehabilitate invaded riparian ecosystems, recover native species, and conserve biological diversity.
5. Develop knowledge and tools to mitigate invader effects on native species and habitats in tropical island ecosystems.

Why Terrestrial Animals Need To Be Included in the Invasive Species Strategy Plan

Invasions by nonindigenous species threaten nearly 50 percent of imperiled native species in the United States and are the Nation's second leading cause of species endangerment after habitat destruction and degradation (Wilcove et al. 2000, Wilson 2002). Population and ecosystem effects by invasive species include disease, predation, competition, parasitism, hybridization, alteration of disturbance regimes, alteration of nutrient cycles, and alteration of hydrologic cycles, all of which can affect terrestrial animal species (Mack et al. 2000).

Native animals are adapted to habitats composed of native plants. Invasion and conversion of native habitats by nonnative plant species can have detrimental effects on animal species by altering habitat quality through alterations in habitat structure, hiding and shading cover, food abundance, arthropod emergence cycles, nesting and denning substrates, animal species composition, predation rates, parasitism rates, and competitive interactions. Animal population responses to invaded or converted habitats can include species population declines, reduced species productivity, behavioral changes, disruptions in breeding cycles, emigration, and endangerment of populations or species.

We need to understand the relationships between changes in plant communities caused by invasions and animal populations to develop habitat restoration and management plans. Regulatory laws such as the Endangered Species Act, Migratory Bird Research and Management Act, and National Environmental Policy Act require that effects on animal populations be evaluated before altering or restoring habitats through management actions. Thus, managers need research information about the status of animal populations before and during restoration and management of invaded habitats. In addition, many terrestrial animal species, such as the brushtail possum (*Trichosurus vulpeculia*) and the brown tree snake (*Boiga irregularis*), are known to be highly invasive once introduced and are identified as "injurious" by the U.S. Fish and Wildlife Service, requiring regulation under the Lacey Act.

Mobile animal species can carry and spread the etiological agents of emerging diseases such as West Nile virus and avian influenza virus. Knowledge of animal behavior, infection rates, and patterns of movement and migration of infected animals is needed to reduce animal mortality rates and prevent spread of diseases to humans. Mobile animal species also disperse seeds, thus potentially furthering the spread of nonnative plant species. Development of knowledge of animal movement and seed dispersal patterns may help predict patterns of species invasion and prevent further spread.

Some animal species may have adapted over time to the presence of nonnative species, and restoring habitats to their original condition can have negative consequences to the native animal species, particularly if it is endangered. We need to better understand the potential negative consequences of restoration to mitigate such effects.

What Is the Unique Role for the Forest Service Today?

- The Forest Service manages a wide network of national forests and grasslands for natural resources, ecosystem services, and recreation. These public lands provide diverse habitats for numerous animal species. The Forest Service must safeguard its wildlife resources as it has been entrusted to do by the public. Nonnative species are identified as the second greatest cause of species imperilment (Wilcove et al. 2000). The Forest Service is mandated by regulatory law and by forest plans to manage wildlife and their habitats, prevent and reduce threats to wildlife, and avoid endangering species.
- Wildlife viewing is a leading recreational pastime on national forests and grasslands. Reductions in wildlife viewing opportunities caused by invasive species jeopardize the trust the public places in Forest Service stewards.

- Forest Service research stations have scientists who have first-hand experience in developing knowledge focused on animal species and habitats, including the adverse relationships among invasive species, animal populations, and management practices. Scientists can readily adjust their research focus to accommodate emerging issues associated with invasive issues when funding is available.
- Forest Service researchers have an extensive network of partnerships and specialized agreements and collaborations with universities, other research organizations, and multiple Federal, State, and municipal management agencies. Through existing and future collaborations, Forest Service researchers can develop knowledge that is critical for solving invasive species problems relative to terrestrial animal species.
- The Forest Service manages numerous experimental forests and ranges and multiple research natural areas that are conducive to experimental studies of wildlife and invasive species.
- The Forest Service has formed partnerships with managers of Long-Term Ecological Research Sites and National Ecological Observatory Network (NEON) Core Sites, which have the infrastructure for monitoring long-term and broad-scale trends in native and nonnative plant and animal populations. Invasive species issues are a research challenge identified by NEON.
- Many invasive species/wildlife problems are situated in urban-wildland interfaces, where urban forest institutes and ecosystem management units managed by Forest Service Research and Development can readily address them.
- Litigation over wildlife species issues produces gridlock for Forest Service managers as they attempt to implement forest and rangeland management actions. Failure to address invasive species/wildlife issues will likely lead to further gridlock.

Who Are Our Customers?

Customers seeking knowledge about the relationships between invasive species and terrestrial animal species include land managers and professionals from numerous land and natural resources agencies, including those from the National Forest System, State and Private Forestry, and International Forestry. In addition, agencies that regularly approach us to develop research studies, obtain information, or consult on best management practices include the Bureau of Land Management, USDA Agricultural Research Service and the Natural Resources Conservation Service, U.S. Fish and Wildlife Service, National Park Service, Bureau of Reclamation, Bureau of Indian Affairs, Native American Tribes, Army Corps of Engineers, Department of Defense, National Wildlife Refuges, State fish and wildlife agencies, State parks, conservation districts, city open space managers, and many more.

We supply information directly and through extension services to assist private and research ranches, managers of leased allotments, irrigators, users of water rights, city planners, and extension service customers. We offer knowledge, funds, training, jobs, and internships to students at multiple educational levels. Numerous nongovernmental organizations, such as The Nature Conservancy, National Wildlife Federation, Defenders of Wildlife, Hawks Aloft, Partners in Flight, Ducks Unlimited, and the Rocky Mountain Elk Foundation, and recreational users, such as birdwatchers, comprise a significant portion of our customer base. Professional societies, such as The Wildlife Society, Ornithological Societies of North America, and Society for Conservation Biology, use our research information for publishing purposes and to develop science-related policy. Our scientists are invited to host society meetings, give keynote talks, and contribute scientific presentations. Our publications, ideas, and models are cited extensively in the scientific literature by other researchers. Conservationists use our information when making recommendations for managing wildlife, habitats, and ecosystem services.

Invasive species are a global problem aggravated by a global market. The Forest Service needs to greatly expand its role as an international steward by reaching out to international customers and developing nations with research information about problems and solutions regarding invasive species.

Key Future Issues

Many of our customers currently are based in rural areas. We will continue to have many of the same or similar agency customers in the future, but customer demand for our research can be expected to shift from rural communities to urban populations as rural areas become urbanized and exurban populations expand into wild lands.

Advanced communication technologies and globalization of trade have rapidly expanded our range of customers, but we have not capitalized on or appropriately recognized our role as international stewards. Our Nation's increased access to world markets is paralleled by a rapid increase in natural resource problems. One of the most significant problems associated with globalization is biotic homogenization (i.e., the ecological replacement of native species with widespread exotics) (Lockwood et al. 2000). Increases in human population growth are also increasing greenhouse gas emissions, resulting in global climate change (IPCC 2007) that has the potential to alter distributions of invasive and native species.

In 15, 30, or 50 years, we may be focusing more of our time and funds on research directed toward the following:

- Protecting wildlife species from endangerment in invaded urban and urban-wildland interfaces.
- Understanding and managing plant and animal species invasions and consequent habitat losses associated with climate change and global warming.
- Managing riparian habitats and riparian-obligate animal species affected by invasions linked to water management practices such as flood control, surface water diversions, and ground water pumping.
- Managing and preserving sensitive or vulnerable ecosystems that act as uninvaded islands having high biological diversity, endemic animal species, or endangered populations of native animal species.
- Restoring wildlife habitats damaged by introduced insect species, such as Africanized honeybees (*Apis mellifera scutellata*), or degraded by invasive plant species that alter nest substrates and habitat structures.
- Restoring wildlife habitats prone to outbreaks of fire associated with plant invasions.
- Recovering endangered species affected by conversion of native habitats to monotypic vegetation composed of an alien plant species.
- Managing animal populations in fragmented, suburbanized deserts and rangelands invaded by species such as buffelgrass (*Pennisetum ciliare*) and lovegrass (*Eragrostis* spp.).
- Managing urban-wildland interface corridors used by animals that spread the seeds of invasive plants.
- Managing land fragments and habitat remnants vulnerable to plant invasions and habitat conversions that result in loss of critical wildlife habitat.
- Mitigating the effects of fragmentation-induced invasions on animal and native plant populations.
- Detecting and managing the spread of diseases and viruses carried by, infecting, or killing wildlife species.
- Detecting and eradicating or intensively managing suites of invasive and affected native species based on advanced technologic capabilities for detecting "hotspots" and native/invasive relationships (Hof et al. 2006, Stohlgren et al. 2006).
- Understanding how patterns and movement of genes and organisms across the landscape affect biodiversity, ecosystem function, and the spread of infectious diseases and invasive species.
- Understanding the role of outbreaks of insects, such as gypsy moth (*Lymantria dispar*), Africanized honey bee, and hemlock woolly adelgid (*Adelges tsugae*), in altering wildlife habitat.

The Future of Prevention and Prediction

- One of the single most important aspects of prediction and prevention is preventing new invasions in otherwise uninvaded areas, such as wilderness, national parks, and other refuges, followed by identifying other areas at high risk but currently low impact.
- Enhance our understanding of the mechanisms causing invasions that affect or involve terrestrial animal species to enable prediction of invasions and improve current risk assessments.
- Develop monitoring tools and methods for predicting and preventing the entry and emergence of harmful invasive animal species, such as Africanized honeybees, invasive rodents, brown tree snakes, java sparrows (*Padda oryzivora*), and others under the Lacey Act and listed on the Federal Register Notices.
- Develop strategies to predict and prevent the introduction and spread of animal species (e.g., rats, snakes, toads, birds) that are likely to be invasive based on knowledge of the invasive potential of introduced related species from similar climate zones.

- Likewise, develop strategies to predict and prevent the introduction and spread of invasive plants, insects, and diseases that negatively affect and endanger wildlife species and local populations based on what has been learned from earlier outbreaks of similar species.
- Enhance our understanding of attributes that make terrestrial animal communities or their natural habitats most susceptible to invasion and provide guidelines to reduce the vulnerability of communities to invasion.
- Develop treatment options to discourage nonnative species invasions following natural disturbances such as wildfires and fuel treatments.
- Model the influences of disturbance history, topography, geography, precipitation and temperature patterns, and climate change on the distributional relationships among invasions, biological diversity, and patterns of species endangerment.
- Develop models and knowledge to predict how drought, hurricanes, global warming, and fire influence outbreaks of invasive pests harmful to wildlife and their habitats.
- Communicate with the public about invasive species, such as feral pets, horticultural plants, and diseases dispersed by animals, and develop support and understanding of the importance of early prediction and prevention.

The Future of Detection and Eradication

- Develop tools and methods for detecting, prioritizing, and eradicating invasive plant and insect species that have the potential to harm or endanger wildlife species either directly by increasing mortality rates, indirectly by reducing habitat quality or availability, or broadly by reducing overall biological diversity.
- Identify priority geographical areas for treatment of invasive species based on sensitivity of wildlife species to harmful invasions or based on numbers of wildlife species that could be negatively affected.
- Develop tools and methods for detecting and eradicating harmful invasive animal species such as Africanized honeybees, invasive rodents and snakes, nutria (*Myocastor coypus*), and barred owls (*Strix varia*) that colonize new areas, where they may decimate habitats or key habitat components, or parasitize, hybridize, weaken, compete with, prey upon, kill, or replace native species.
- Develop spatial maps of occurrence of individual invasive species and concentrations of species and overlay these with maps of native animal species concentrations to determine priority locations for focusing eradication efforts.
- Develop tools, models, and protocols for detecting and monitoring new invasive species populations and their rates of spread in relation to wildlife population responses.
- Communicate and collaborate with local, State, national, and international networks to detect, monitor, manage, and mitigate invaders that have a harmful effect on threatened, endangered, and sensitive wildlife species.

The Future of Management and Mitigation

- Develop tools to prioritize invasive species for control based on the extent to which they damage habitats required by native terrestrial animal species; negatively affect native species richness and biological diversity; disrupt timing and availability of food supplies; damage trophic relationships; affect keystone species; and jeopardize sensitive, threatened, and endangered species.
- Develop, compare, or refine tools to more effectively manage invasive species populations for the purpose of restoring and improving habitats for affected native wildlife species, maintaining native biological diversity, re-establishing ecosystem linkages, and recovering threatened and endangered species.
- Develop tools to prioritize invaded areas deemed as critical to the conservation and recovery of wildlife habitats, native plant communities, and animal species at risk of local extinctions.
- Develop and evaluate tools for timing treatments to maximize efficacy and minimize side effects on nontarget native wildlife species.
- Assess and describe the relationships among plant invasions, fire, wildlife habitat use, and habitat restoration to reduce fire risk in ecosystems in which plant invasions increase fire frequency (e.g., ecosystems invaded by saltcedar (*Tamarix ramosissima*), cheatgrass (*Bromus tectorum*), buffelgrass, and Lehmann lovegrass (*Eragrostis lehmanniana*) (Cox 1999).
- Refine fundamental knowledge of population genetics and ecology of priority invasive species to reduce their effects on native animal populations.

- Communicate with the public about how invasive species are linked to the imperilment of native animal species and develop support for invasive species management and mitigation based on the public appeal for wildlife.
- Manage travel corridors and dispersal pathways to prevent the spread of animal diseases and facilitate the movement of animal vectors.

The Future of Restoration and Rehabilitation

- Develop ecologically sound restoration methods that consider genetics at population, community, and ecosystem levels of integrity and resistance to reinvasion.
- Evaluate the economic and nonmonetary costs and benefits to native species and biological diversity of restoring and rehabilitating invaded ecosystems (*sensu* Pimentel et al. 2000).
- Develop guidelines for prioritizing populations, communities, habitats, and ecosystems for restoration work to maximize efficacy and efficiency of the restoration efforts under limited resources.
- Obtain public and political support for restoration work to enhance the recovery and maintenance of wildlife habitats and animal populations, especially when the invaded ecosystem may be seen as the attractive norm.
- Develop a scientific basis for restoring and rehabilitating invaded ecosystems, considering the economic and value-added benefits to wildlife populations, recreational animal species, endangered species, and biological diversity.
- Reduce or eliminate factors in restored wildlife habitats that increase risk of reinvasion and ensure that critical components, such as food supplies and nest substrates affected by invasions, are restored for use by animal populations.
- Determine the relationships and interactions among natural disturbance regimes (e.g., fire, flooding, hurricanes, drought), species invasions, and animal survival requirements and restore disturbances found to be useful in suppressing invasions and sustaining native animals and their habitats.

The Future of Application and Communication

We need to improve our methods for disseminating research tools and information. Peer-reviewed publication of scientific results must be followed up with translation of research results into more generalized and user-friendly products. Tools should be translated into brief explanatory products that can be disseminated through brochures, Internet Web sites, and other means that more effectively reach managers and the public. Scientists need to coordinate and collaborate with State and Private Forestry and university extension services to exploit these infrastructures for more effective dissemination of important new findings and tools to a broader customer base.

We can expect increasing use and demand for our research information by multiple cultures as the ethnic composition of our Nation changes in response to growing and immigrating populations of Hispanic, Asian, and other people. Changes in human population demographics will cause shifts in our role over time. Our role will likely become increasingly oriented toward the needs and demands of urban, suburban, and exurban populations whose interests may be nontraditional, more diverse, and dictated by socioeconomic status. Differences in socioeconomic background may explain differences in how communities interact with their external environment. For example, compared with wealthier, racially mixed neighborhoods, impoverished and ethnically segregated urban areas tend to have more impoverished bird communities dominated by exotic bird species (Melles 2005). This situation is related to the amount and types of vegetation planted in neighborhoods, including whether the planted species are native and whether community planting programs are available.

We need to use advanced communication technologies to convey information about invasive species to people in developing countries. We cannot afford to isolate ourselves by ignoring our role as international stewards. Our Nation's problems with invasive species are global problems. The global spread of invasive species is leading to the worldwide impoverishment of biological diversity.

It would behoove the Forest Service to direct communication, funding, and educational efforts toward global, urban, and underserved communities, enabling them to gain an increased appreciation of and concern for the natural world as well as an understanding of the harm associated with the introduction of

nonnative species. We can evolve to meet local community demands and global needs by (1) changing our workforce to match the types of customers we serve, (2) reaching out more effectively to convey information about invasive species to diverse communities and worldwide users, and (3) seeking to understand how diverse cultural, economic, immigrant, and international backgrounds can be used to guide program delivery about the economic and ecological costs of invasive species.

Top Five Priorities

1. Develop knowledge and tools to manage and mitigate effects of invasive species facilitated by globalization, urbanization, and climate change on distributions and abundances of native animal species.

Global change involves rising numbers of human immigrants and travelers, increased world trade, and advances in global communication and transportation (McNeeley 2000), all of which increase the probability that new alien pests, including plants, insects, rodents, reptiles, birds, predators, and viruses, will "hitchhike" or intentionally be released into the United States. Global change influences the scale and tempo of change in health risk pertaining to invasive viruses and diseases (McMichael and Bouma 2000). Perhaps the greatest hidden danger from invasive species is their contribution to "global homogenization," a process linked to factors ranging from communication technology to consumer mentality (McNeeley 2000). Biotic homogenization is the preferential loss of native species across taxons, or within taxonomic groups (e.g., global avifaunas), followed by ecological replacement with widespread exotics (Lockwood et al. 2000). Homogenization affects the abundance and distribution of species and the functioning of ecosystems (Collins et al. 2002). To retard the rate of global homogenization of species, future research will need to devote more attention to developing tools and methods for (1) detecting immigrating pests, viruses, and diseases that are known or have the potential to spread rapidly, jeopardizing or infecting not only humans but also native animals (including vulnerable species and disease vectors), and (2) preventing them from establishment in the United States.

Increased human activity (e.g., development) is correlated with the ecological imperilment of species (Brown and Laband 2006). Urbanization increases road density, air travel, bike and pedestrian travel, construction, and overall human activity in a given area, resulting in new pathways and wildland entry points available for dispersal of invasive species. Urbanization disturbs soil surfaces, introduces feral or escaped populations of domestic plants and animals, increases the frequency of human-caused fire outbreaks, and fragments and converts habitats. Cumulative disturbance in urban and exurban environments facilitates introductions and rapid spread of new invasive species, resulting in habitat fragmentation and reduced biological diversity (Hansen et al. 2005). Increased human population growth also accounts for increased urban warming and the development of urban "heat islands" that can attract invasive species. In addition, global rise in human activity increases the greenhouse effect, primarily through release of carbon dioxide (CO_2) emissions. Recently observed global warming is believed by many to be caused by greenhouse gas emissions from industry, transportation, and agriculture (IPCC 2007).

Patterns of species richness of native and nonindigenous plants and animals are correlated with each other and with geographical patterns of precipitation and air temperature (Stohlgren et al. 2006). Consequently, changes in climate may cause changes in the geographical distributions and concentrations of invasive and native species and may alter the susceptibility of habitats to future invasions by new nonnative species. Increasing CO_2 emissions due to human population growth can be expected to induce distributional changes in native and nonnative species either through direct effects (e.g., on photosynthetic processes) (Dukes 2000) or through effects of global warming. Global warming in combination with escalating human use of surface and ground water supplies will likely warm soils and dry waterways in some regions of the country, fostering the ability of xeric-adapted invasive species to colonize new areas and expand their ranges. The Forest Service needs to be proactive in predicting, detecting, and managing invasions and habitat losses related to changes in climate, water supply, and consumer use of water.

2. Develop knowledge and tools to improve management effectiveness and minimize unintended side effects.

The effectiveness of invasive species management and management tools (e.g., herbicides, biological control agents, fuels management) needs to be assessed for their suitability in sustaining wildlife populations, protecting biodiversity, and restoring wildlife habitats and food supplies. Most management tools cause disturbances that can facilitate invasions. All

management tools, including invasive species tools, inevitably have side effects. In general, these side effects decrease with increased specificity of the management tool, but even highly specific management tools can affect native species through complex interactions (Pearson and Callaway 2003).

Invasive plant management can endanger threatened species, as in the case of the southwestern willow flycatcher, or even increase risk of human disease, as in the case of hantavirus, if not carefully applied (Dudley and Deloach 2004, Pearson and Callaway 2006). As noted by the Office of Management and Budget review of the Forest Service invasive species program, a foremost need in invasive species management now and in the future is better knowledge of our management tools and the systems we are working with to ensure that management actions improve conditions without creating more problems.

3. Develop knowledge and tools for managing invaded woodland, desert, steppe, and grassland ecosystems to conserve native species.

Old-world invasive grasses now dominate many Great Basin, Mojave, and Sonoran Deserts (Brooks and Pyke 2002), and old-world forbs are disrupting western grassland systems of the Columbia River Basin and Great Plains. Exotic grasses include the annuals cheatgrass, red brome (*Bromus rubens*), Mediterranean grass (*Schismus barbatus*), and medusahead (*Taeniatherum caput-medusae*) and the perennials buffelgrass, fountain grass (*Pennisetum setaceum*), natal grass (*Melinis repens*), and Lehmann lovegrass. These species have altered fire regimes, shortening the fire return interval. Exotic forbs include the knapweeds, leafy spurge (*Euphorbia esula*), St. Johnswort (*Hypericum perforatum*), and many others that affect wildlife populations by disrupting vegetation communities. All these invasive species thrive in post-fire landscapes.

Greater sage grouse (*Centrocercus urophasianus*) once ranged through 13 Western States and 3 Canadian provinces, but populations have declined at an overall rate of 2 percent per year from 1965 to 2003, and only about 56 percent of grouse presettlement range is currently occupied (Connelly et al. 2004). Invasive species, particularly cheatgrass and West Nile virus, pose threats to sage grouse and their habitats. Sage grouse are considered obligates of sagebrush (*Artemesia* spp.) and require large, connected landscapes of sagebrush, grasses, and forbs for their lekking, breeding, and feeding activities. Of the historical sagebrush habitat, 31 percent has been converted to other vegetative cover, including areas invaded by alien species (Connelly et al. 2004). Cheatgrass invasion shortens the fire-return internal, reducing or eliminating fire-sensitive sagebrush (Pyke 1999). Other sagebrush bird species are also threatened by alien plant invasions (Knick et al. 2003). West Nile virus, another alien invader, represents a significant new threat to sage grouse and other at-risk bird species (DeLach 2006, Naugle et al. 2004). Research is required to develop tools and protocols for restoring and rehabilitating sage grouse habitats, reducing the amount of historic range now infested by cheatgrass, and developing measures for safeguarding sage grouse populations from infection by West Nile virus.

Spotted knapweed (*Centaurea stoebe*) and other exotic forbs have radically transformed large regions of western grasslands. Reductions in native plant abundance and diversity by these species have reduced forage for big game species and domestic livestock and eroded native food chains for songbirds by reducing invertebrate foods (Ortega et al. 2006, Trammell and Butler 1995). Buffelgrass and Lehmann lovegrass have spread throughout arid environments of Arizona. Buffelgrass chokes out native species and increases the frequency of fires in the Sonoran Desert. Fires kill native old-growth cactus, including endemic saguaro (*Carnegiea gigantea*), an important source for cavity nests of the endangered cactus ferruginous pygmy owl (*Glaucidium brasilianum cactorum*), and endemic palo verde (*Cercidium floridum, C. microphyllum*), which is used as a nest tree by many endemic bird species. Birdwatching is an important form of tourism in the Sonoran Desert environments near Tucson, where species richness of endemic and unusual bird species is remarkably high. Bock and Bock (1986) found that conversion to lovegrass communities at a Sonoran Desert site reduced numbers of species of birds, rodents, and grasshoppers. Desert tortoise (*Gopherus agassizii*) is both directly and indirectly affected by invasive plants and the fires that they cause (Brooks and Pyke 2002). In areas of recurrent fire, desert tortoise is completely absent. New studies are needed to determine the relationships among grass invasions, fire, and endemic wildlife species.

Broadleaf herbicides can be used to effectively control invasive forbs over local areas, but there is a need to better understand how best to deploy these herbicides to maximize their effectiveness at controlling target invaders and minimize their side effects on nontarget species. Some herbicides have been developed to suppress graminoids, but many are problematic due to

their lack of specificity to the target invasive grass, which can result in effects on desired native grasses. Moreover, many of the serious problem grasses have achieved a scale of invasion that far exceeds effective control using herbicides. Biological control has proven effective for numerous widespread invasive forbs but less so for grasses, and biological control successes are generally sporadic. More research would advance our understanding of efficacy in biocontrol, particularly as it relates to problematic grasses. The use of grazing and fire as effective management tools for some exotic grasses and forbs should be explored further.

4. Develop knowledge and tools to manage and rehabilitate invaded riparian and wetland ecosystems, recover native species, and conserve biological diversity.

Riparian and wetland habitats have disproportionately high species richness of terrestrial animals, especially birds, relative to the percent of land area they encompass. But in many areas, these habitats are now becoming havens for many invasive species (Stohlgren et al. 1998). Invasions have the potential to impoverish the fauna inhabiting riparian and wetland communities. Even though less than 6 percent of the Earth's land mass is wetland, 24 percent of the world's most invasive plants are wetland species (Zedler and Kercher 2004). Many riparian and wetland invaders form monotypes that alter habitat structure, lower biodiversity, change nutrient cycling and productivity (often increasing it), and modify food webs. Wetlands are landscape sinks that accumulate debris, sediments, water, and nutrients, all of which facilitate plant invasions by creating canopy gaps or accelerating the growth of opportunistic plant species. Residential development and associated habitat fragmentation also increase vulnerability of riparian areas to nonnative plant invasions (Lussier and Da Silva 2005).

In the Southwest, elimination of spring flood events has reduced recruitment in cottonwood populations along many rivers and streams, allowing invading plants, such as saltcedar and Russian olive (*Elaeagnus angustifolia*), to establish on sites formerly occupied by native cottonwoods and willows. As surface water availability declines, native riparian plants senesce and invasive plants replace them. Under these conditions, desert bighorn sheep (*Ovis canadensis nelsoni*) populations and other native wildlife generally decline (Lovich and de Gouvenain 1998).

Accumulation of woody debris, combined with dense stands of invasive woody plants in the understory, has led to fuel loadings capable of supporting catastrophic wildfires (Busch 1995). Sensitive and endangered species such as southwestern willow flycatcher (*Empidonax traillii extimus*) and yellow-billed cuckoo (*Coccyzus americanus*) depend on the presence of riparian vegetation. Fires destroy their nests, lowering their local productivity and recruitment rate. Fires destroy cottonwoods used by riparian cavity-using species, such as *Myotis* bats, woodpeckers, kestrels, Bewick's wren (*Thryomanes bewickii*), ash-throated flycatcher (*Myiarchus cinerascens*), and nuthatches, and platform nesters, such as owls, buteos, and accipiters, which require large tree species to build nests and reproduce. Invasive woody species are unsuitable as nest sites for these animals. Fire kills cottonwoods, resulting in early emergence of a critical food source (cicadas) for birds and other wildlife (Smith et al. 2006). Fire facilitates replacement by invasive plants. Managers lack information on the interactive and long-term effects of invasive plants, fires, and flood control on sensitive wildlife species and their habitats.

In California and other subtropical regions, giant reed (*Arundo donax*), a nonindigenous perennial grass, aggressively invades riparian areas, changing vegetation structure, reducing availability of perch and nest sites, and reducing numbers, total biomass, and taxonomic richness of aerial insect species (Herrera and Dudley 2003). Alteration of food supply reduces the habitat value of riparian areas to bird species and other animals whose diets are largely composed of insects found in native riparian vegetation. Endangered species obligated to riparian zones include least Bell's vireo (*Vireo bellii pusillus*) and southwestern willow flycatcher. Both species are threatened by habitat loss caused by giant reed invasion.

Land managers need increased understanding and improved tools to deal effectively with the complexity of interacting problems created by invasions in riparian ecosystems. Current restoration and rehabilitation methods for riparian areas are often not compatible with goals for recovering endangered animal species or conserving species diversity. New research could provide alternative approaches for managing riparian ecosystems to enable conservation of animal species.

5. Develop knowledge and tools to manage invasive and native species and habitats in islands and island ecosystems.

Because island faunas have evolved in isolation, they are especially sensitive to invasive exotic species of competitors, predators, and parasites to which the island dwellers have few

or no defenses. Introductions of rats, dogs, cats, pigs, goats, and mongoose (*Herpestes javanicus*), as well as other animals associated with human colonization, have caused extinctions and still continue to threaten Pacific and Caribbean island species. On the island of Guam, 9 of 11 forest-dwelling bird species were extirpated following the arrival of the brown tree snake in the early 1960s. Similarly, Hawaii's endemic bird populations were extirpated in the lowlands in the 1880s as the result of the accidental introduction of mosquitoes that transmitted bird pox and avian malaria to which the natives lacked immunity.

Invasive exotic plants can also negatively affect island wildlife populations, especially those that change the environment they invade. A typical example is that of the invasive exotic grasses, which are highly susceptible to wildfires and change the fuel load such that intensive wildfires become more likely. The grasses recover quickly from fires in contrast to woody vegetation that recovers slowly, if at all, and the resulting wildfire cycle impedes forest regeneration. This type of problem is of special concern in Hawaii and Puerto Rico, where forest areas are limited and vulnerable to additional anthropogenic and natural (e.g., hurricanes) disturbances, further stressing threatened and endangered island wildlife (e.g., Puerto Rican nightjar (*Caprimulgus noctitherus*), yellow-shouldered blackbird (*Agelaius xanthomus*). Other invasive exotic plants on islands, such as Australian pine (*Casuarina equisetifolia*), Brazilian pepper (*Schinus terebinthifolius*), and *Leucaena,* are quick to colonize newly disturbed sites and can displace and dominate native early successional plant species of importance to wildlife. Such invasions are of concern for the endangered neotropical migrant Kirtland's warbler (*Dendroica kirtlandii*) on its island wintering grounds, where invasive exotic species displace native plants bearing fruit consumed by the warbler.

Island ecosystems are often easily invaded and colonized by exotic species, in part because island biotas are poorly adapted to compete with or evade newly arriving species. A recent example comes from Hawaii, where the coqui frog (*Eleutherodactylus* spp.) introduced from Puerto Rico has successfully established lowland populations that now have densities three times higher than those found in Puerto Rico, presumably due to the absence of coqui predators on Hawaii. The success of exotic colonists on islands is evident in Puerto Rico's resident breeding bird species of which 25 percent are alien or exotic species: 31 species of exotic birds are established as breeders; 5 exotic species are found in the wild, but breeding has not been established. Exotic birds pose a threat to native species because they have the potential to transmit diseases directly; serve as a reservoir for diseases transmitted by arthropod vectors; and/or elevate pathogen levels, enabling them to persist in higher than normal concentrations.

The threat of disease transmission from an exotic bird species is of special concern for the endangered Puerto Rican parrot (*Amazona vittata*), which is a species for which high disease susceptibility is predicted. The recent (2005) evidence for the mosquito-transmitted West Nile virus in birds on Puerto Rico demonstrates that research to more effectively predict, detect, and manage such threats to the parrot and other endangered species is of critical importance.

Another newly arrived invasive exotic to threaten the Puerto Rican parrot is the Africanized honeybee that appeared in the 1990s. The Africanized honeybees have hybridized with the previously naturalized European honeybees (*Apis mellifera*), resulting in a more aggressive colonizer of tree cavities used for nesting by parrots and other wildlife. The potential exists to deter bee colonization of nest cavities, as preliminary research by the International Institute of Tropical Forestry indicates that pheromones may prove useful as a deterrent to bee colonization.

Although long established as exotics since the arrival of Europeans, rats continue to threaten island wildlife throughout the world, and control programs continue to this day. Rats are also predators of threatened and endangered frogs, lizards, and snakes, including the Puerto Rican (*Epicrates inornatus*) and Virgin Island (*E. monensis granti*) boas. In addition to the direct effect that black rats may have on island wildlife, they may indirectly affect wildlife by changing forest plant composition, as a result of their consumption of seeds. Despite its potential importance, the role of black rats (*Rattus rattus*) as seed predators influencing tree recruitment and subsequent forest composition has yet to be studied in island or tropical ecosystems.

In summary, because of the high rates of colonization and establishment of exotic species facilitated by human activities, island ecosystems are ideal laboratories for studying invasive exotics and their potential effects. These studies are required for the recovery of endangered island species, and, in many instances, the findings from such studies are of relevance to the

study and management of invasive exotics elsewhere, such as in the Southern United States.

For similar reasons, other types of isolated "island-like" ecosystems are also at greater risk to effects of invaders than "mainland" systems. Examples include sky islands resulting from mountains in desert environments, islands in large lakes and river systems, and habitat patches isolated by development. In each case, unique (in some cases, endemic) fauna may experience greater threats from invasions, in part, because they may be associated with small populations and small habitat areas that are surrounded by potential invaders.

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The Role of the Forest Service in Aquatic Invasive Species Research

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Abstract

Aquatic ecosystems include the most imperiled taxa in the United States, and invasive species are the second leading contributor to this imperilment. The U.S. Department of Agriculture (USDA), Forest Service is legally mandated to sustainably manage aquatic habitats and native species on National Forest System (NFS) lands. Invasive species add complexity and uncertainty to natural resource management, and, thus, invasive species research is needed to guide effective, science-based management of aquatic systems. Although Forest Service Research and Development (R&D) scientists have much expertise to apply, aquatic invasive species research has not been an agency focus. We identify areas in which the Forest Service is well positioned to contribute research that other organizations are not addressing. Increasing agency emphasis on aquatic and riparian invasive species research and adding expertise in several areas (e.g., risk assessment, genetics, and several taxonomic areas) would facilitate a shift toward the Forest Service providing more valuable science and leadership in this arena. We identify some key general research needs; however, a more formal process, bringing Forest Service aquatic and riparian scientists together, perhaps with key NFS biologists and other stakeholders, is necessary to effectively identify and prioritize specific research needs. Some of the top research needs we identify include the following:

- Develop new prediction and ecological risk assessment tools and conduct risk assessments for priority invasive species and habitats.
- Collaborate on or establish a central data management repository.
- Increase understanding of ecological, physical, and biological factors facilitating and inhibiting invasions.
- Develop new prevention, eradication, and control tools.
- Enhance role of social sciences in aquatic invasive species research.
- Improve communications. Bring Forest Service R&D scientific expertise to bear on aquatic invasive species policy and regulation. Improve communication with NFS and other biologists and the public.

Importance of Aquatic and Riparian Invasive Species

Aquatic and riparian-associated species constitute the Nation's most imperiled biota, with the five most imperiled groups residing in freshwater and riparian habitats (fig. 1). Invasive species are the second most important factor in this imperilment, contributing to the declines of about one-half of the imperiled species (fig. 2). Invasive species can harm native communities via competition, predation, hybridization, and habitat alteration and as sources and vectors of alien pathogens. Species invasion is a global problem, and an international perspective is necessary to effectively address many invasion issues.

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