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THE INVASIVE SPECIES SURVEY: A REPORT ON THE INVASION OF THE NATIONAL WILDLIFE REFUGE SYSTEM

A Technical Report for the National Wildlife Refuge System, May 2004

THE INVASIVE SPECIES SURVEY: A REPORT ON THE INVASION OF THE NATIONAL WILDLIFE REFUGE SYSTEM

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and the staff of the USFWS National Wildlife Refuge System

SUMMARY

Between 2002 and 2003, we solicited invasive species information from the U.S. Fish and Wildlife Service's (USFWS) National Wildlife Refuge System. Managers, administrators, and biologists responded to an electronic survey providing detailed information on 432 refuges, representing about 90% of the units. Over 80% of wildlife refuges recognized problems with more than 670 invasive organisms. Specifically, refuges reported 432 non-native plant species, 194 non-indigenous animal species, and 36 plant and animal diseases of concern. Widespread invasive species include Canada thistle on 63 refuges and European starling on 53 refuges; both species occur in six of the seven USFWS Regions. Hakalau Forest National Wildlife Refuge in Hawaii reported the highest numbers of invasive species: 59 non-native plant species, 33 non-indigenous animals, six wildlife diseases, and three plant diseases. Across the National Wildlife Refuge System, a lack of basic inventory data is evident in the survey responses. While 300 refuges control invasive species, fewer than 200 refuges report efforts to monitor invasive species, and nearly all refuges lacked baseline data on plant and wildlife diseases. This document generally describes survey results, and an on-line database accesses the detailed survey information such as the distribution of invasive species, control techniques, and contact information. The internet tool also provides lists of invasive species near each refuge that could increase early detection and rapid response capabilities. Warning of what might invade, combined with an understanding of the invasive species problem across the country, can provide the foundation for a more strategic invasive species program for the National Wildlife Refuge System.

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INTRODUCTION

In this report, we describe the results of the National Wildlife Refuge System (hereafter referred to as the "Refuge System") Invasive Species Survey. In 2002-2003, we conducted an electronic survey of all federally designated USFWS National Wildlife Refuges to assess the current status and management of invasive non-native plant species, non-indigenous animals, and diseases of plants and animals (Figure 1). In this report, we present a summary of survey responses from managers, administrators, and biologists representing 432 national wildlife refuges. This represents about 90% of the organizational units with direct land management responsibilities (Figure 2).

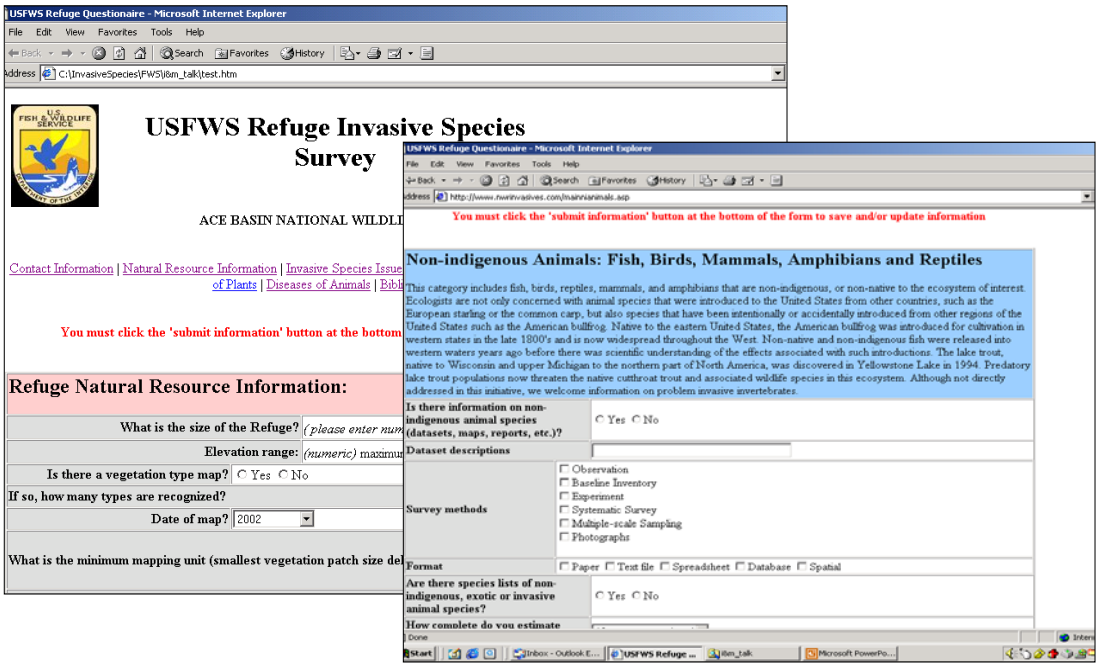


Figure 1. *Refuge staff across the nation provided detailed responses on natural resources and invasive species concerns through the web-based National Invasive Species Survey.*

This review of the survey results is based on over 670 non-native plant species, non-indigenous animal species, and emerging diseases that were reported by refuge managers, biologists, and administrators. The Refuge System addresses numerable natural resource issues, but we are confident that the shared experiences of managers will promote greater success with invasive species management. This information is available to the Refuge System through user-friendly, on-line databases with custom search capabilities to access survey information at local, regional, and national scales (www.nwrinvasives.com; and see Accessible and Usable Information). This invasive species web portal for the Refuge System contributes to improved support for management action on the refuges and informed decision-making at local, regional, and national levels. These survey results, with the added value of other national-scale datasets, will highlight the Refuge System as a leader in the invasive species challenge.

It is our hope that instant access to "live" datasets will encourage a shift in invasive species management from reaction to prevention.

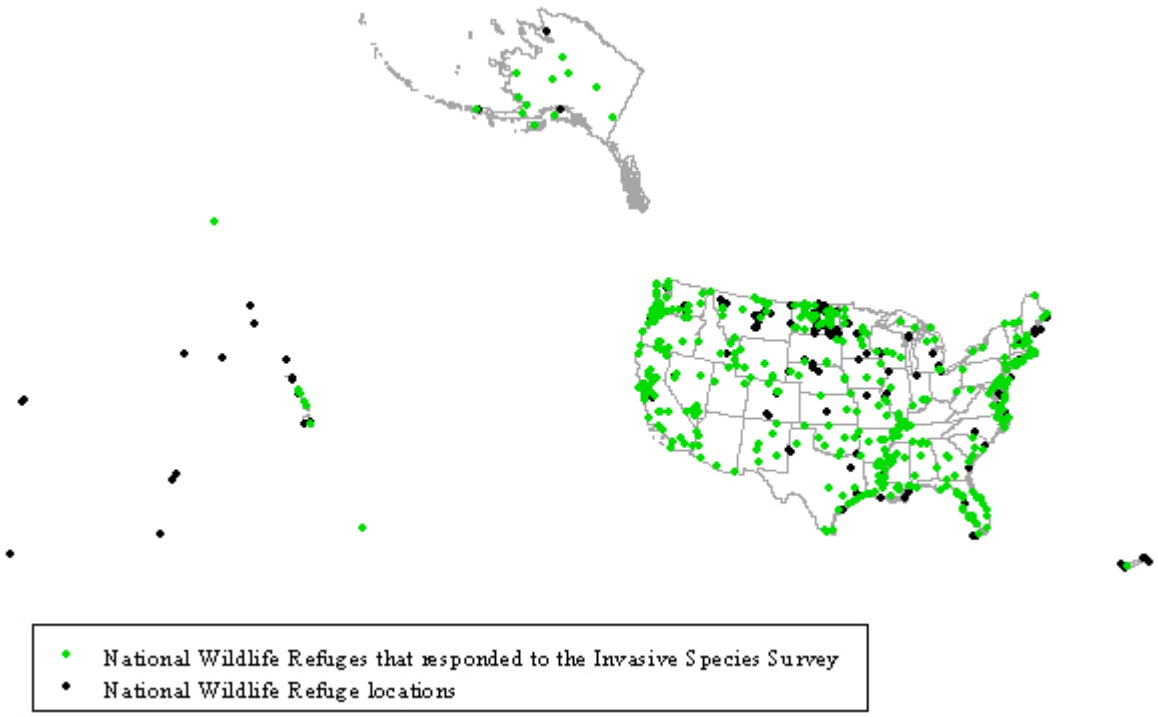


Figure 2. *Map of the National Wildlife Refuge System locations, with green circles indicating the 432 refuge areas represented in the National Invasive Species Survey.*

BENEFITS OF THE NATIONAL INVASIVE SPECIES SURVEY

We envision this information contributing to improved management of invasive species problems at many, if not all, of the refuges. Determining the occurrence and location of species invasions is an essential part of planning and taking action. Combining reports of known invasive species, suspected invaders, and vulnerable habitats, will allow for the Refuge System to assess data for completeness and define priorities to bridge information gaps. Use of the internet to distribute the survey results provides managers with a resource for control techniques, will ease coordination among refuges facing common issues, and may provide a mechanism for sharing limited resources like teams and equipment for control. One of the most important benefits is the development of predictive invasive species lists based on other national-scale datasets. Synthesis of available information around each refuge allows for an efficient approach to inventory, monitoring, and control efforts and provides a platform for cooperation with partners on adjacent landscapes. Understanding the commonality of issues faced by managers will provide opportunity to increase the effectiveness and efficiency of efforts to control or mitigate the impacts of invasive species.

STATUS OF NATURAL RESOURCES INFORMATION

The goal of this survey was to move beyond documentation of known invasive species problems in order to prevent future invasions in the world's largest network of public lands and waters set aside specifically for the protection of wildlife. Despite the additional time required of refuge managers, we requested baseline information on natural resources. This was critical to assess the status of available information and to develop an early warning system for vulnerable habitats and regions. General natural resource information is essential for interpretation of survey responses because areas administered by the Refuge System range from vast wilderness to suburban landscapes. Refuge System staff will benefit from this information as they face threats and conflicts in managing natural resources.

The diverse habitat types and resources in the Refuge System serve as ecological benchmarks at national and global scales. Staff reported refuges ranging in size from one-half of an acre to over 26 million acres (reported by Yukon Delta NWR staff). These lands and waters represent all of the 27 cover type categories used in the survey, a subset of the National Vegetation Classification Standards (NVCS; http://www.fws.gov/data/gisveg.html). About 70% (310) of the respondents have access to at least some GIS capabilities, while just 33 refuges have a current vegetation map that complies with the recently adopted NVCS. The completeness of invasive species reports from a refuge is dependant on the availability of natural resource information, such as species lists. Species lists have been compiled for birds at 325 refuges, while only 17 and 6 refuges, respectively, report documentation of animal and plant diseases (Figure 3).

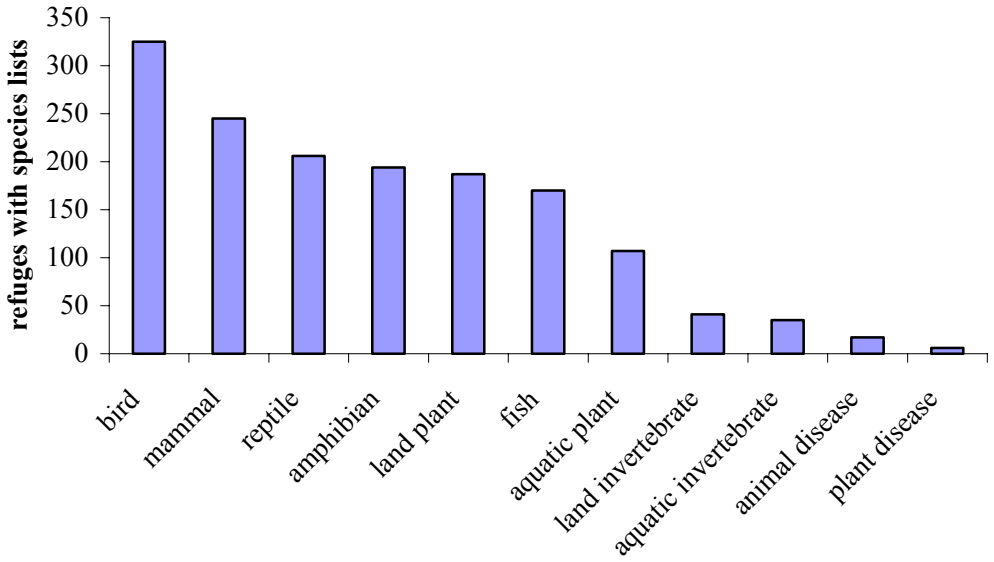


Figure 3. *Number of refuges that have species lists for different groups of native and non-native plants, animals, and diseases, from a total of 432 responses.*

INVASIVE SPECIES IN THE REFUGE SYSTEM

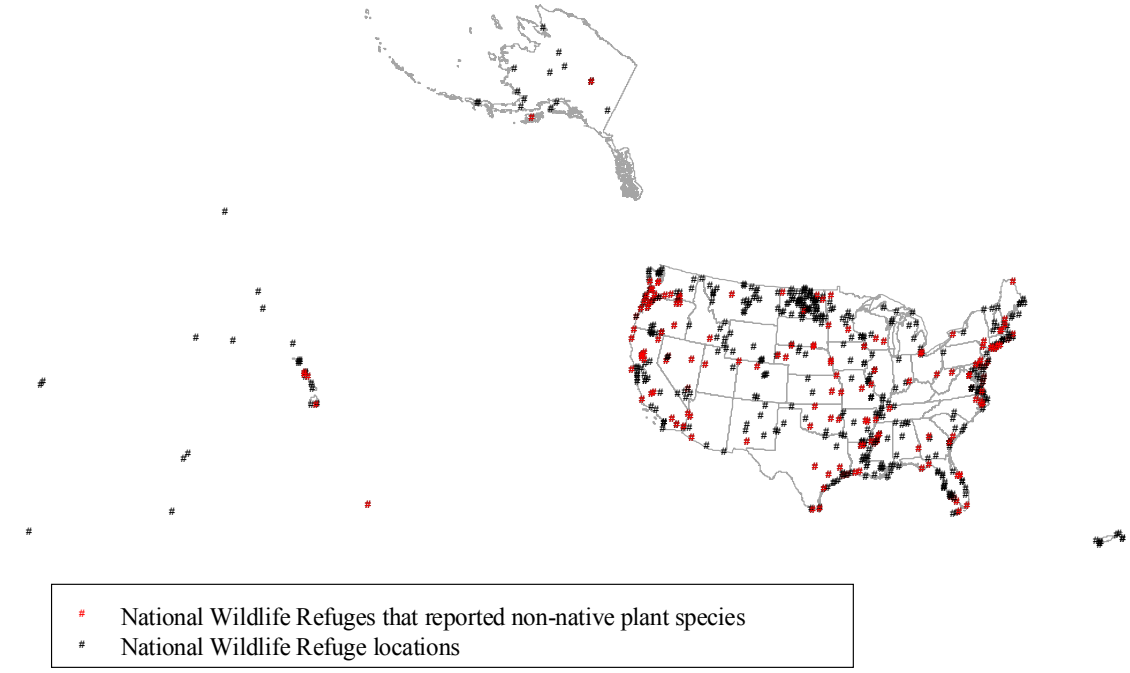
Of the 432 responses submitted by refuge staff, more than 80% included reports of known problems with invasive species. Those that did not report problems often cited a lack of information due to inaccessibility of remote refuges or lack of support for field surveys. Management action to control invasive species was reported from at least 301 refuges, while invasive species are monitored on just 196 refuges. Just over half of the responses (227) included concerns about invasive species on lands adjacent to refuges, including 212 refuges that reported species they suspect will soon be established, many of which (157) have identified source populations. Staff of 158 refuges reported non-native species that are not currently considered to be a problem, such as crops or managed fish and game populations. Although the majority of invasive species mentioned in this report are not native to North America, the term "non-indigenous" is used to describe invasive animal species because in several cases there is concern over unnatural range expansions of North American species. Of all the habitat types across the Refuge System, upland and wetland perennial grassland areas were among the most frequently invaded (197 and 148 refuges, respectively).

We requested detailed information on established invasive species and control efforts. Staff of 171 refuges listed non-native plant species, 135 listed non-indigenous animal species, 36 listed diseases of animals and 12 listed pests or diseases of plants (Figures 4 and 5). The highest number of non-native plant species reported was 59 from Hakalau Forest NWR on the Big Island of Hawaii, followed by Cypress Creek NWR in Illinois (40). Hakalau Forest NWR also reported the most diseases affecting animals (6) and plants (3). The highest number of non-indigenous animal species reported was 41, from the Silvio O. Conte NWR on the Connecticut River in Massachusetts.

In total, responses included reports of 432 unique, non-native plant species, 194 non-indigenous animal species, 36 animal diseases, and 9 plant diseases. The most frequently reported non-native plant species was Canada thistle (*Cirsium arvense*; 63 refuges in six regions). A native to Europe, Canada thistle is an aggressive, creeping perennial weed that can invade crops, pastures, and natural lands. The frequency of reporting reflects plasticity; Canada thistle invades and reduces native species diversity in all parts of the U.S. except the Southeast (www.ext.colostate.edu). European starling (*Sturnus vulgaris*) was the most frequently reported non-indigenous animal species (51 refuges in six regions; See Appendix 1). All of the more than 200 million European starlings in North America originated from the same one hundred individuals released in New York City's Central Park in the late 1890s (www.birds.cornell.edu). They have since spread to Florida, the Pacific coast, and Alaska.

Fewer diseases were reported. The most frequently reported animal diseases were West Nile virus (*Flavivirus spp.*, eight refuges in Regions 3, 4, and 5; see Region 5 sidebar) and avian botulism. Avian botulism results from the ingestion of toxin produced by the bacterium *Clostridium botulinum* (including Types A and C), reported from 13 refuges in Regions 1, 3, 5 and 6. Dutch elm disease (*Ceratostomella ulmi*) was the most reported plant disease (6 refuges in three regions). The low rates of response for diseases of plants should not be equated with a minimal threat to the Refuge System. Not a single refuge reported sudden oak death fungus (*Phytophthora ramorum*), even from coastal

areas in California where the pathogen is known to cause tree mortality in the same or surrounding counties.



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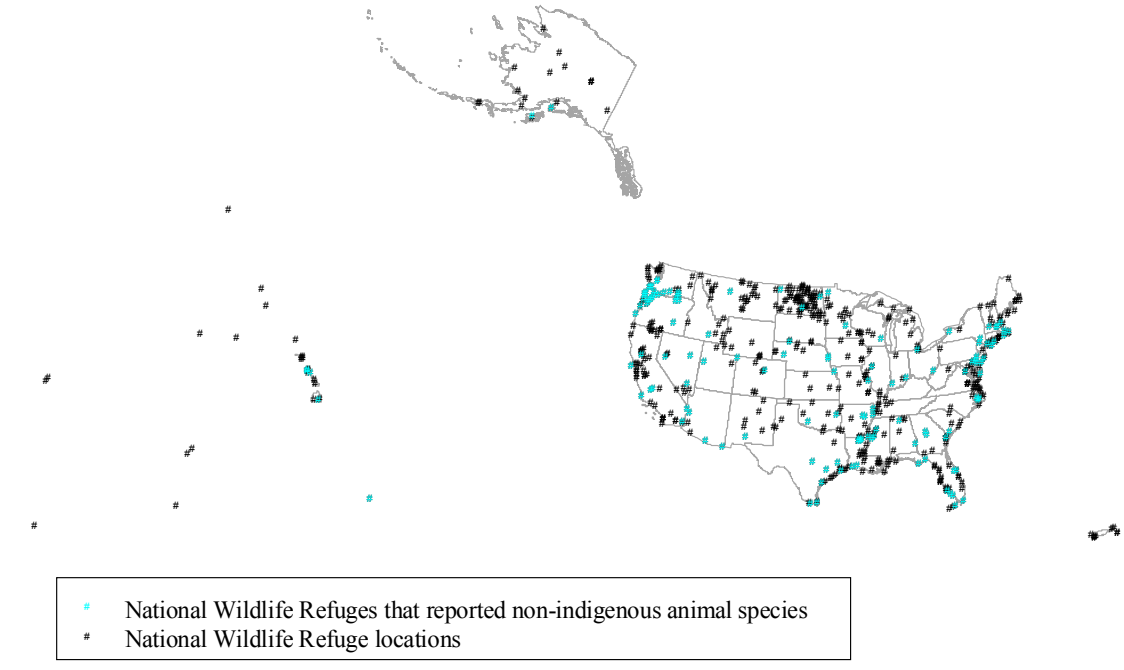

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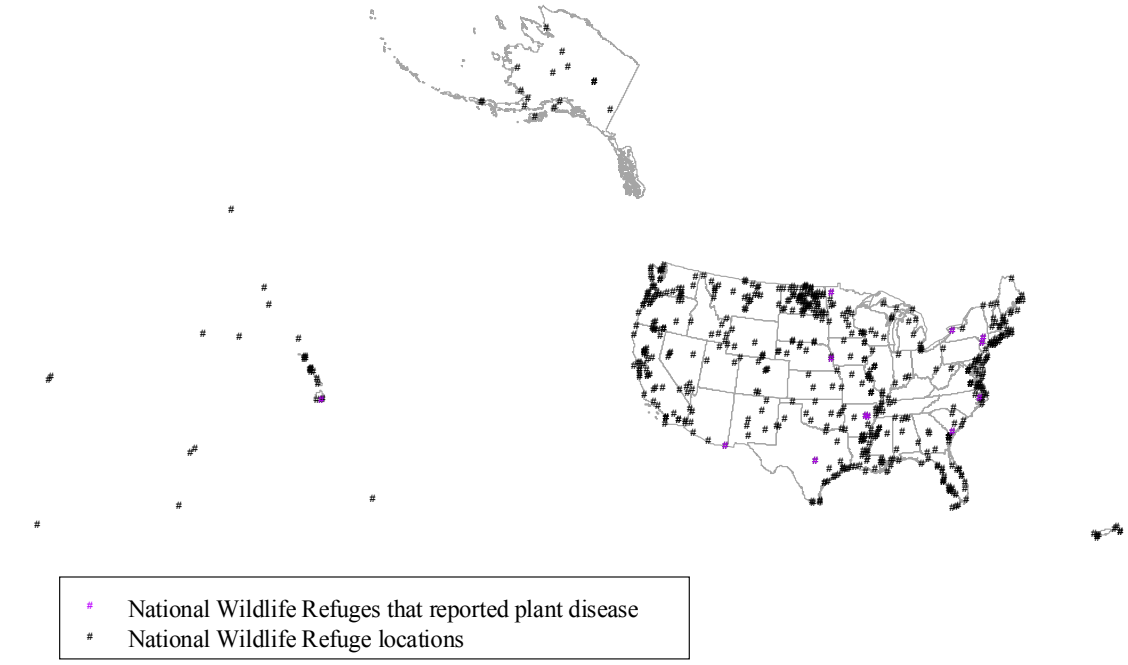
Figure 4. *Maps of the Refuge System locations (black circles), with colored circles indicating refuges reporting non-native plants (a) and non-indigenous animals (b).*



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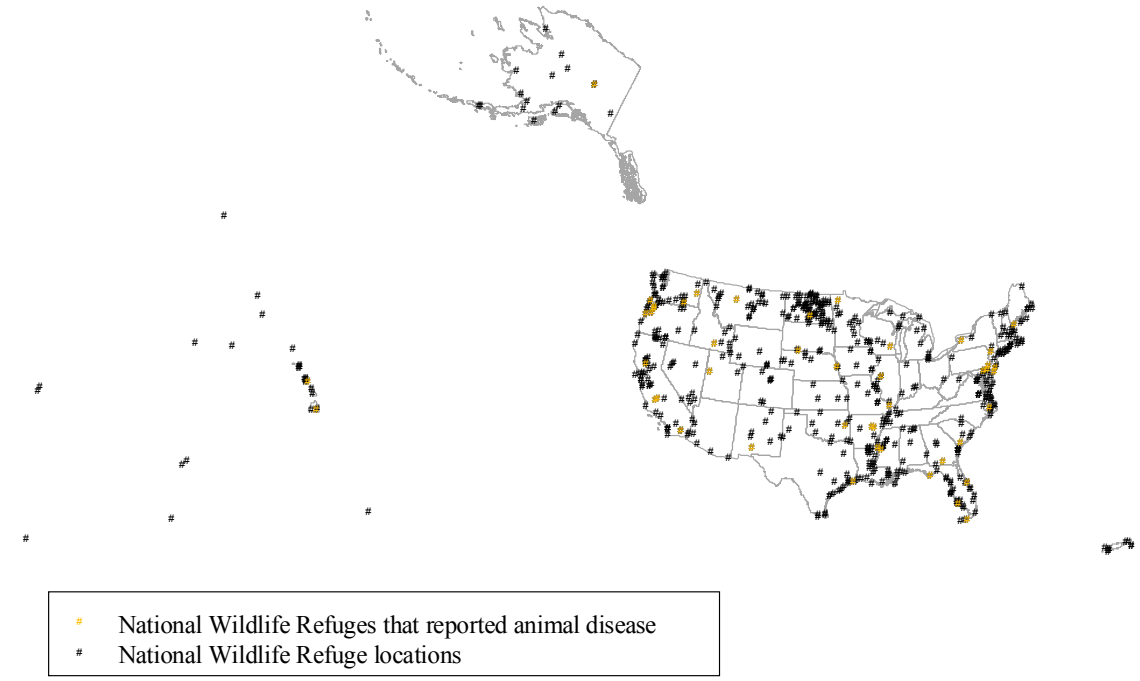

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Figure 5. *Maps of the Refuge System locations (black circles), with colored circles indicating the refuges reporting specific diseases of plants (a) and animals (b).*

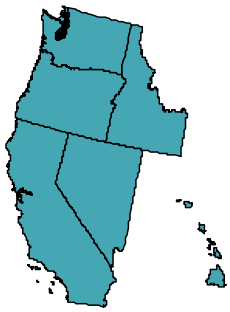
REGIONAL SURVEY RESULTS

Survey responses describe the extent of the invasive species problem confronting the refuge system: the distribution of information, inventory and control work; hot spots of invasion; and refuge vulnerability. Perhaps most importantly, survey responses highlight the similarities of the invasion problem across the Refuge System. Within and across regions, refuges share many invasive species problems, and reports suggest many of the same rare and unique habitats are frequently invaded. Furthermore, examples of synergistic effects among invading plants, animals, and diseases support a multiple-species data synthesis approach (Simberloff and Von Holle 1999). The non-native plants, non-indigenous animals, and diseases of plants and animals mentioned in the following sections are by no means a comprehensive or prioritized list of invasive species that threaten the Refuge System. Rather, they provide examples of the many threats and problems caused by the spread of invasive species in the Refuge System, including competitive displacement or crowding, predation and herbivory of native species, hybridization with native species, transmission of disease, and dramatic changes in ecosystem processes.

Note: The total number of refuges listed reflects best lists available and may include wetland management districts and other unique management units in addition to standard National Wildlife Refuge units.

Region 1 - Pacific Region

NWR Units: **118**
Survey Responses: **100**
Refuges with Invasive Species Problems: **85**
Refuges Reporting Non-native Plant Species: **53**
Total Number of Non-native Plant Species: **195**
Refuges Reporting Non-indigenous Animal Species: **39**
Total Number of Non-indigenous Animal Species: **78**
Refuges Reporting Plant Disease: **1**
Total Number of Plant Diseases: **3**
Refuges Reporting Animal Disease: **14**
Total Number of Animal Disease: **14**



With the exception of a few remote island refuges that are inaccessible and under-studied, all responses from Region 1 acknowledged invasive species problems. Refuges throughout California, Nevada, Idaho, Oregon, and Washington reported dozens of known problem non-native plant species, invasive species on adjacent lands, and species that they suspect may soon establish.

The myriad of invasive species issues on Hawaii and other Pacific Islands merits special attention (see http://www.hear.org/). The Refuge System faces many of these issues as it contains some of the finest remaining stands of native montane rain forest and other important wildlife habitats in Hawaii and the Pacific Islands. Staff of these refuges commented that they had too many suspected invaders to list, and stated “Hawaii is the

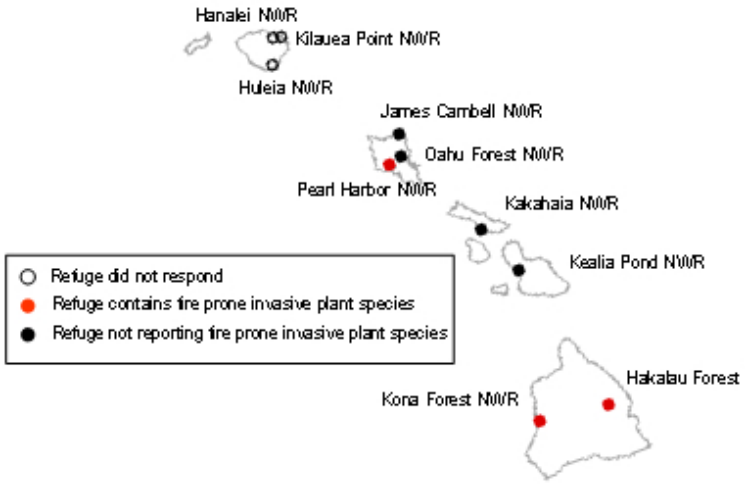
invasive species capital of the world." Hawaiian ecosystems have been affected by non-native plants that crowd out native species and alter ecosystem processes; diseases that are carried by non-indigenous animals and spread by introduced mosquitoes; competition from non-indigenous animal species for food and space; and predation by rats, cats, and mongooses that threaten native animals and plants.

The most commonly reported non-native plant in Region 1 (and across the Refuge System) was Canada thistle (Appendix 1). The second and third most reported plant species, reed canary grass (*Phalaris arundinacea*) and perennial pepperweed (*Lepidium latifolium*), are examples of invasive species that have controversial origin and native range. In some cases, genetic research may be needed to identify invasive non-native genotypes, or hybridization of species. Regardless of whether or not they are native to North America, it is important to note that they are of concern to refuge staff. Cocklebur (*Xanthium ambrosioides*) is another species that may be native to some areas of North America but is a troublesome weed and is poisonous to a variety of animals. Scotchbroom (*Cytisus scoparius*), salt cedar (*Tamarix spp.*), yellow star thistle (*Centaurea solstitialis*), purple loosestrife (*Lythrum salicaria*), Himalayan blackberry (*Rubus discolor*), and bull thistle (*Cirsium vulgare*) were documented on many refuges and are suspected to establish on others.

The most commonly reported non-indigenous animal in Region 1 was the bullfrog (*Rana*

Grass Invasions, Ecosystem Alterations

Increased fire frequency in Hawaii demonstrates the capacity of an invasive species to alter ecosystem properties. Unlike many areas across the West, fire does not seem to have played an important evolutionary role in most native ecosystems of the Hawaiian Islands, and relatively few Hawaiian endemic plant species possess adaptations to fire (Mueller-Dombois 1981). Lightning is uncommon on oceanic islands, and many native ecosystems may have lacked adequate fuel to carry fires ignited by lightning or vulcanism. Fires in modern Hawaii are mostly human-caused, fueled primarily by non-native grasses, and generally highly destructive to native plant species.



Distribution of fire prone non-native plant species.

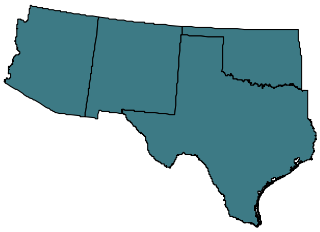
Invasion by non-native grasses adds fine fuel capable of carrying fire to previously fire-free sites (Tunison et al. 2001). Invasive grasses recover rapidly after fire, increase flammability of the site, and become increasingly dominant after repeated fires (D'Antonio and Vitousek 1992, D'Antonio et al., 2001). The culprits include non-native grass species such as beard grass and buffelgrass, that were among the many non-native plants listed for refuges in Hawaii. Non-native grasses, such as buffelgrass, are also known to accelerate fire regimes and alter native desert tortoise habitats in the Sonoran desert of Arizona (Region 2; Esque and Schwalbe 2000).

catesbiana). While bullfrog larvae eat organic debris, algae, plant tissue, suspended matter, and small aquatic invertebrates, the adults are voracious predators that consume any animal that can be swallowed, even snakes, birds, fish, crawfish, and other frogs. There is some evidence that bullfrogs and non-native fish can alter habitat conditions in a way that facilitates the success of each other (Adams et al. 2003). Other commonly reported animals in Region 1 include the European starling, common carp (*Cyprinus carpio*), nutria (*Myocastor coypus*), domestic cat (*Felis catus*), brown-headed cowbird (*Molothrus ater*), house mouse (*Mus musculus*), house sparrow (*Passer domesticus*), various sunfish species, and western Canada goose (*Branta canadensis*).

Plant diseases are an emerging issue in Region 1. Although known occurrences are few, Hakalau NWR reported three different plant pathogens. Early detection monitoring has been effective in many areas of California, but cryptic invaders, such as sudden oak death fungus, could spread undetected and establish in a variety of habitats. Avian botulism and many other pathogens of wildlife were reported from Region 1.

Region 2 - Southwest Region

NWR Units: **51**
Survey Responses: **38**
Refuges with Invasive Species Problems: **38**
Refuges Reporting Non-native Plant Species: **17**
Total Number of Non-native Plant Species: **80**
Refuges Reporting Non-indigenous Animal Species: **15**
Total Number of Non-indigenous Animal Species: **49**
Refuges Reporting Plant Disease: **2**
Total Number of Plant Diseases: **1**
Refuges Reporting Animal Disease: **3**
Total Number of Animal Disease: **5**



Many invasive species are pervasive in Region 2. Chinese tallow tree (*Sapium sebiferum*), salt cedar, Bermuda grass (*Cynodon dactylon*), Johnsongrass (*Sorghum halepense*), giant reed (*Arundo donax*), Japanese honeysuckle (*Lonicera japonica*), Chinaberry (*Melia azedarach*), giant salvinia (*Salvinia molesta;* Figure 6), and buffelgrass (*Pennisetum ciliare*) were commonly reported non-native plant species on the refuges and on adjacent lands (see Appendix 1). Frequently reported non-indigenous animals in Region 2 include feral hog (*Sus scrofa*), western mosquitofish (*Gambusia affinis*), nutria, house sparrow, American bullfrog, European starling, common carp, donkey (*Equus asinus*), domestic cat, and Mediterranean gecko (*Hemidactylus turcicus*).

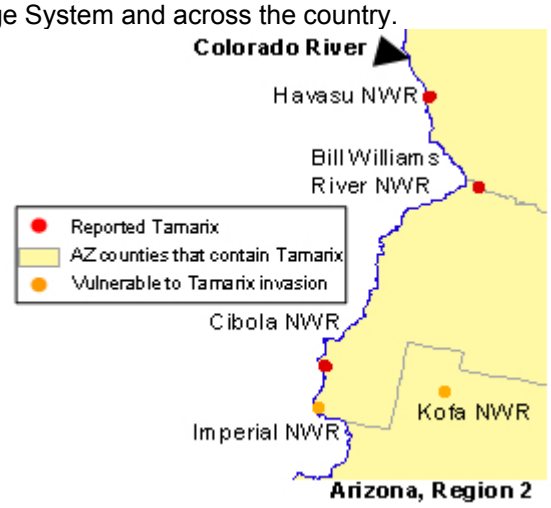
Giant salvinia leaves in hand (left), and covering a lake (right), photo: John Randal, The Nature Conservancy

Salt Cedar – Invading the Riparian Oasis

Salt cedar (*Tamarix spp*.) is a persistent invader of riparian corridors throughout the Southwest. Pervasive monocultures displace native cottonwood and willow (*Salix spp.*) communities crucial to a myriad of native wildlife species. Many refuges in Region 2 exist to protect some of these remaining native riparian systems, but salt cedar is invading (reported in six Region 2 refuges), and populations both up and downstream threaten other refuges.

Many control techniques exist, and some work better than others. Recent introductions of a biological control (the beetle *Diorhabda elongata* released to six southwestern states in 2001) had marginal success at Stillwater NWR in Oklahoma. Similarly, several refuges found hand pulling and cutting resulted in vigorous re-growth. However, the combination of cutting and chemical treatments (foliar and cut-stump application of herbicides such as Garlon-4, Arsenal, and Weedar-64) received "excellent" reviews. Removal of salt cedar with bulldozers and similar heavy equipment also works, but successful techniques are expensive and require many hours of work.

The magnitude of the salt cedar invasion and the monumental eradication expenses may require a cooperative approach. Refuges along the Colorado River could share the cost of control crews and equipment. Another approach might be to request changes in river flow. Staff at several refuges report that methods to restore or simulate natural hydrological processes may be the most effective control of salt cedar and would encourage cottonwood and willow regeneration at the same time. History and economics enlarge the scope of this challenge, but spirit of cross-refuge and interagency collaboration that is supported by this Invasive Species Survey is an essential piece to control salt cedar and other invasive species in the Refuge System and across the country.



Containment of non-native plants (e.g. saltcedar, giant salvinia), and non-indigenous animals (e.g. red imported fire ants (*Solenopsis wagneri*), nutria) is a primary problem. The non-native aquatic plant giant salvinia can rapidly cover the surface of lakes and streams (Figure 6). The oblong floating leaves measure ½ to 1 ½ inches, but aggregate to form floating mats that shade and crowd out native plants. Thick mats reduce oxygen content and degrade water quality for fish and other aquatic organisms. Mats impede boating, fishing, swimming, and clog water intakes for irrigation and hydropower. Common in Texas and Louisiana, invasive species biologists recently found established populations of giant salvinia in Lake Wilson on the island of Oahu, Hawaii. With a limited window for control, refuge managers in Hawaii need information on the effectiveness of management approaches from other areas where giant salvina has become a problem. Managers in Regions 2 and 4 reported success with specific mechanical and chemical control methods and their experience could lend assistance to the rapid response programs in Hawaii.

Region 3 - Great Lakes-Big Rivers Region

mgnt areas)
Refuges with Invasive Species Problems: **36**
Refuges Reporting Non-native Plant Species: **13**
Total Number of Non-native Plant Species: **81**
Refuges Reporting Non-indigenous Animal Species: **8**
Total Number of Non-indigenous Animal Species: **27**
Refuges Reporting Plant Disease: **1**
Total Number of Plant Diseases: **1**
Refuges Reporting Animal Disease: **3**
Total Number of Animal Disease: **6**

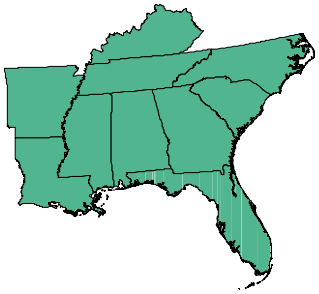
Garlic mustard (*Alliaria petiolata*), Canada thistle, reed canary grass, smooth brome (*Bromus inermis*), musk thistle (*Carduus nutans*), purple loosestrife, multiflora rose (*Rosa multiflora*), leafy spurge (*Euphorbia esula*), common reed (*Phragmites australis*), and Kentucky bluegrass (*Poa pratensis*) are common throughout Region 3. Many of these were also listed as invasive species suspected to establish on refuges where they have not yet arrived.

Seven of the ten most frequently reported non-indigenous animals in Region 3 were aquatic species, including six fish species and zebra mussel (*Dreissena polymorpha*). Common carp, bighead carp (*Hypophthalmichthys nobilis*), white perch (*Morone americana*), round goby (*Neogobius melanostomus*; Figure 7), alewife (*Alosa pseudoharengus*), and goldfish (*Carassius auratus*) were documented from several refuges. These reports reflect the many Great Lakes invasions that have resulted in skyrocketing costs to commercial and recreational fisheries. Since 1990, the round goby has spread rapidly in many areas of the Great Lakes. Native to the Caspian Sea, this aggressive species is adapted to both marine and fresh water. Risk assessment offers the potential to avoid more of these costly introductions (Kolar and Lodge 2002).

Figure 7. *Round goby, Neogobius melanostomus (Pallas 1814), a recent invading fish in the Great Lakes.*
Photo: USGS fact sheet, www.invasivespecies.gov.

Region 4 - Southeast Region

NWR Units: **120**
Survey Responses: **100**
Refuges with Invasive Species Problems: **85**
Refuges Reporting Non-native Plant Species: **32**
Total Number of Non-native Plant Species: **109**
Refuges Reporting Non-indigenous Animal Species: **24**
Total Number of Non-indigenous Animal Species: **40**
Refuges Reporting Plant Disease: **4**
Total Number of Plant Diseases: **2**
Refuges Reporting Animal Disease: **6**
Total Number of Animal Disease: **16**



Alligator weed (*Alternanthera philoxeroides*), Brazilian pepper (*Schinus terebinthifolius*), Japanese honeysuckle, Chinese tallow tree (*Sapium sebiferum*), Johnsongrass, hydrilla (*Hydrilla verticillata*), common reed, cogon grass (*Imperata cylindrical*), Japanese climbing fern (*Lygodium japonicum*), and Chinese wisteria (*Wisteria sinensis*) have been documented from many refuges and adjacent lands. Nutria, feral hog, red imported fire ant, coyote (*Canis latrans*), nine-banded armadillo (*Dasypus novemcinctus*), European starling, brown anole (*Anolis sagrei*), domestic cat, Cuban tree frog (*Osteopilus septentrionalis*), and the oscar cichlid (*Astronotus ocellatus*) were frequently reported from Region 4 refuges. Chestnut blight (*Endothia parasitica*) also likely affects plant species in the Southeast refuges.

Hydrilla occurs on at least five refuges in Region 4, and staff at many other refuges expect invasion from established populations on adjacent lands. The current range of hydrilla is primarily in the southeast United States. Hydrilla's ability to grow in more temperate waters (Figure 8) means it will probably spread to higher latitudes; it has been found up the eastern seaboard as far north as Cape Cod, Massachusetts, and in California and Washington on the West Coast. The Region 5 (northeast) staff did not report occurrences, but experts in New England

Synergistic Invaders

Avian vacuolar myelinopathy (AVM) is a neurological disease that kills bald eagles, coots, and several other species. First discovered in 1994, the Center for Wildlife Health of the US Geologic Survey considers AVM an "emerging" and important wildlife disease. Recent investigation suggests that AVM may be linked to plant invasion and changes in habitat caused by hydrilla. Little is know about the etiology of the disease, but it appears to stem from toxin-producing microbes living on hydrilla and other submergent aquatic plants (Dr. Tonie Rocke, *pers. comm.*, 2003, Research Epizootiologist, U.S. Geological Survey, National Wildlife Health Center).

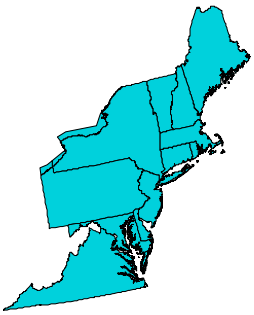
Refuges did not report an occurrence of AVM, but Piedmont NWR in Georgia is only one county away from an AVM outbreak in Monroe County, Georgia. Piedmont NWR did report the presence of hydrilla. Other refuges in close proximity to outbreaks of AVM include Bond Swamp NWR, Pee Dee NWR, and Carolina Sandhills NWR, but these refuges either did not respond to the survey or did not submit non-native plant lists. All refuges in Region 5, and especially refuges invaded by hydrilla, should initiate monitoring of AVM, and pursue control of hydrilla in hopes of preventing the occurrence and spread of this duo of cross-taxa invaders.

have identified hydrilla as the most serious threat to natural aquatic communities in the area (UCS 2003). For more on hydrilla's ecology and distribution, see http://nas.er.usgs.gov/plants/docs/hy_verti.html.

Figure 8. *Hydrilla plant shoots (inset) and infested river. Photos: Dave Spencer and John Randall respectively, The Nature Conservancy.*

Region 5 - Northeast Region

NWR Units: **75**
Survey Responses: **60**
Refuges with Invasive Species Problems: **50**
Refuges Reporting Non-native Plant Species: **33**
Total Number of Non-native Plant Species: **99**
Refuges Reporting Non-indigenous Animal Species: **21**
Total Number of Non-indigenous Animal Species: **67**
Refuges Reporting Plant Disease: **3**
Total Number of Plant Diseases: **1**
Refuges Reporting Animal Disease: **5**
Total Number of Animal Disease: **5**



Numerous non-native plants have invaded refuges across Region 5. Many refuges reported the presence of common reed, multiflora rose, Japanese honeysuckle, purple loosestrife, Canada thistle, Japanese barberry (*Berberis thunbergii*), Asiatic bittersweet (*Celastrus orbiculatus*), Japanese knotweed (*Polygonum cuspidatum*), autumn olive (*Elaeagnus umbellate*), and tree of heaven (*Ailanthus altissima*).

Purple loosestrife is one of many beautiful and showy species that escaped gardens and rapidly spread throughout natural areas, reflecting the challenges of introductions through horticultural trade (Reichard and White 2001). This invasive non-native plant occurs in at least 13 refuges in Region 5, 28 refuges across the country, and county data from the Biota of North America Program confirms staff concerns that it may have established, or is likely to establish, at many more locations (Figure 9). Plant characteristics, such as attractive nectar flowers, may also facilitate non-native plant species spread through changing interactions among pollinators or seed dispersers. Japanese honeysuckle was reported from 17 refuges in Region 5, as well as from many refuge areas in Regions 2, 3, and 4.

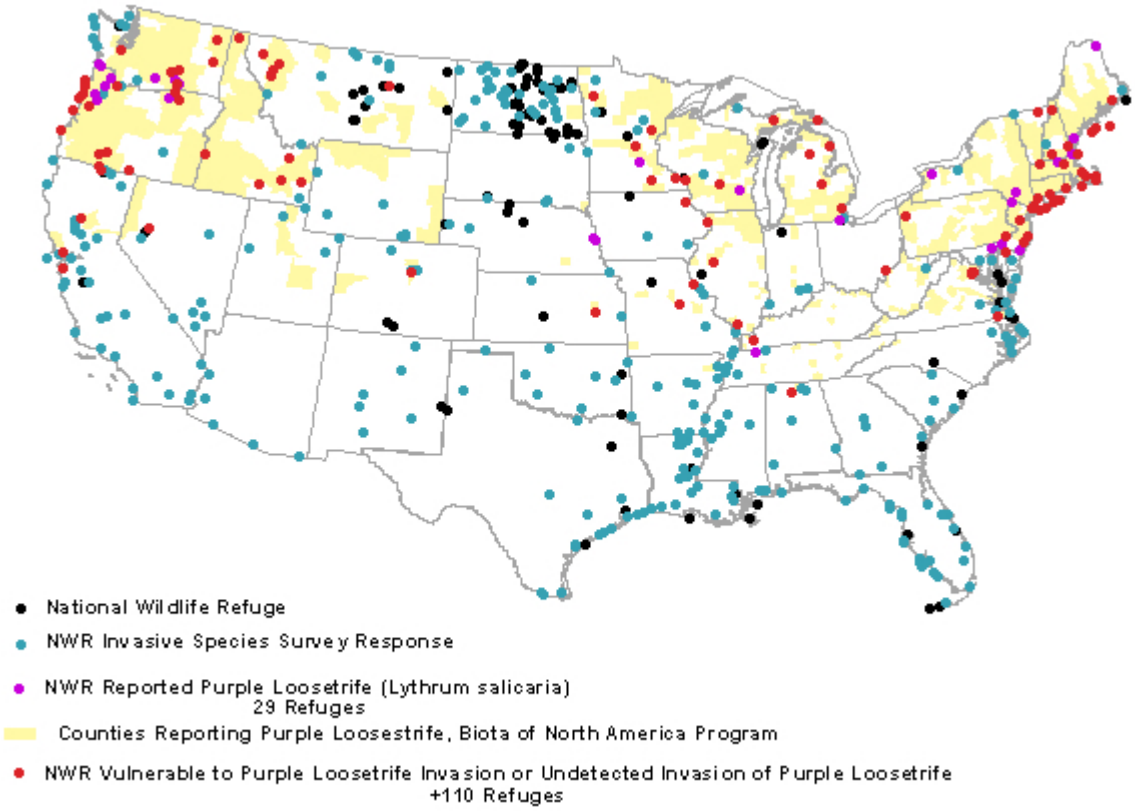


Figure 9. *Map of Refuge System locations, with purple dots indicating the 28 refuges with known occurrences of purple loosestrife, and red dots indicating the 110 locations where the non-native plant is known from the same county.*

Reports indicate that phragmites, or giant reed, has established on 24 refuges, more than any other non-native plant in Region 5 (Figure 10). Across the country, reports exceeded 40 occurrences on refuges in Regions 1, 3, 4, and 5. A native strain in some areas of the country (such as wetland seeps in the West) does not seem to have the invasive characteristics. The rapid spread of the non-native variety illustrates the importance of subtle genetic differences that have important ramifications for native biota and invasion biology (Saltonstall 2002).

Figure 10. *Common reed has invaded to form monotypic stands in many habitats. Aggressive non-native strains can out-compete native strains that may have been present. Photo: John Randall, The Nature Conservancy.*

House sparrow, European starling, and house finch (*Carpodacus mexicanus*) generate concern on several refuges. The house finch is native to areas of western North America, but was introduced and has since expanded in the East. The introduction and spread of a previously unknown strain of the pathogen *Mycoplasma gallisepticum* (causes conjunctivitis in birds) resulted in an epidemic that has reduced densities of house finch populations at many locations. This is just one example of how a bird population with expanding ranges may influence patterns of transmission and spread of avian diseases.

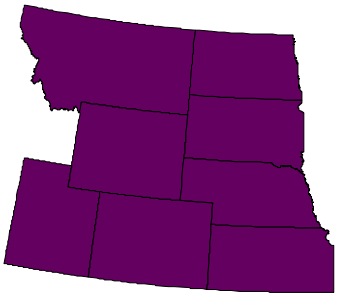
West Nile Virus: A Spreading Threat

West Nile virus first appeared in the USA in 1999 and has since spread by mosquitoes to other animals (Dobson and Foufopoulos 2001). Zoonotic pathogens (diseases of wildlife that can be transmitted to humans), such as West Nile virus are of increasing concern. Vectors include non-native species of mosquitoes, such as *Aedes aegypti* introduced from Africa, and the Asian tiger mosquito (*Aedes albopictus*). The Asian tiger mosquito was first detected in the United States in New York and New Jersey in 1998. Since then, this mosquito has been found in Ohio, Maryland, Connecticut, Massachusetts, Pennsylvania, and Virginia. Expanding ranges of this species and other non-indigenous mosquitoes may influence patterns of West Nile virus spread.

In addition to over 138 species of wild and captive birds, West Nile virus can infect horses, dogs, cats, alpacas, small mammals, alligators, and humans. In 2002 and 2003, the virus was found in wild bird populations (both native and non-indigenous species) throughout the eastern U.S. and in numerous locations in the West. Certain native bird populations may be particularly at risk.

Region 6 - Mountain-Prairie Region

NWR Units: **136**
Survey Responses: **76**
Refuges with Invasive Species Problems: **56**
Refuges Reporting Non-native Plant Species: **22**
Total Number of Non-native Plant Species: **53**
Refuges Reporting Non-indigenous Animal Species: **9**
Total Number of Non-indigenous Animal Species: **23**
Refuges Reporting Plant Disease: **1**
Total Number of Plant Diseases: **1**
Refuges Reporting Animal Disease: **4**
Total Number of Animal Disease: **5**



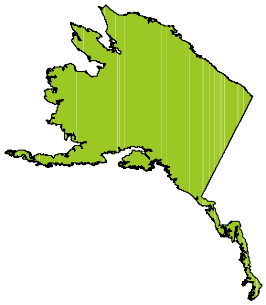
Frequently reported non-native plants in Region 6 included Canada thistle, leafy spurge, musk thistle, crested wheatgrass (*Agropyron cristatum*), smooth brome, Russian olive (*Elaeagnus angustifolia*), Kentucky bluegrass, wormwood sage (*Artemisia absinthium*), eastern red cedar (*Juniperus virginiana*), and perennial sowthistle (*Sonchus oleraceus*). Ubiquitous animal invaders included birds such as ring-necked pheasant (*Phasianus colchicus*), house sparrow, European starling, grey partridge (*Perdix perdix*), chukar partridge (*Alectoris chukar*), rock dove (*Columba livia*), and fish such as common carp, grass carp (*Ctenopharyngodon idella*), and spotfin shiner (*Cyprinella spiloptera*), and the American bullfrog.

Emerging wildlife diseases such as brucellosis (*Brucella spp*.), chronic wasting disease (CWD), and West Nile virus are a concern for staff in mountain-prairie states (Figure 11). The spread of CWD, a transmissible spongiform encephalopathy, causes dramatic economic costs (reduced hunting and wildlife viewing) and ecological costs (declines in populations and genetic diversity). Documentation of transmission, and other keys to control these diseases will depend on the best available data and full cooperative interaction among agencies and the public (Dobson and Foufopoulos 2001).

Figure 11. *Chronic wasting disease (CWD), brucellosis and other wildlife diseases are an emerging problem in mountain and prairie states. Photo: Sara Simonson, NIISS.*

Region 7 - Alaska Region

NWR Units: **16**
Survey Responses: **14**
Refuges with Invasive Species Problems: **2**
Refuges Reporting Non-native Plant Species: **2**
Total Number of Non-native Plant Species: **3**
Refuges Reporting Non-indigenous Animal Species: **1**
Total Number of Non-indigenous Animal Species: **11**
Refuges Reporting Plant Disease: **0**
Total Number of Plant Diseases: **0**
Refuges Reporting Animal Disease: **1**
Total Number of Animal Disease: **2**



The Refuge System administers over 76 million acres in 16 areas of Alaska. Relative to the size of this area, very few refuges reported non-native plants, non-indigenous animals, or animal diseases, and not one refuge reported a plant disease. Managers with limited time and resources had recently responded to surveys of invasive species in wilderness areas of Alaska (Marler 2000, Temple et al. 2003). To address information gaps, this section is a summary of the combined survey responses.

Alaska faces a unique set of invasive species problems characterized by a long history of both intentional and accidental mammal introductions. The Alaska Maritime NWR encompasses hundreds of islands along the coastline of Alaska, many of which are designated wilderness areas. Many of these islands have no native terrestrial mammals; thus native plants and animals are particularly vulnerable to the growing populations of introduced arctic fox (*Alopex lagopus*), ground squirrel (*Spermophilus parryii*), reindeer (*Rangifer tarandus*), cattle (*Bos taurus*), and other non-indigenous mammals. Rats (*Rattus norvegicus*, *Rattus spp.)* were accidentally introduced at many locations in the region through cargo, particularly during WWII, and by shipwrecks. Rats prey on the native birds, and eradication programs have been successfully implemented through interagency cooperation in many areas including several islands in Alaska Maritime NWR.

Southern Alaska is particularly at risk from non-indigenous fish and aquatic invertebrate species because of oil development, commercial industry, and tourist traffic, particularly from points south along the Pacific corridor. Northern pike (*Esox lucieus*) causes problems in many areas, and there is a serious threat of invasion by aquatic invertebrates such as the European green crab (*Carcinus maenas*).

Many Alaskan habitats are considered to be resistant to non-native plant species invasion because of northerly limits to non-native species ranges along a latitudinal gradient, harsh conditions, and short growing season. In many tundra, boreal forest, and coastal areas of Alaska, non-native plant problems were not reported to be a major problem. Although few non-native species were listed in this phase of the survey, 27 non-native plant species have been reported from Alaskan refuges in recent wilderness invasive species surveys (Marler 2000, Tempel et al. 2002; Figure 12). A sample of non-native plants reported from the refuges in Region 7 includes Canada thistle, hoary cress (*Cardaria draba*), leafy spurge, wormwood sage, black mustard (*Brassica nigra*), smooth brome, musk thistle, spotted knapweed (*Centaurea maculosa*), mountain trumpet (Polemoniaceae, *Collomia linearis*), orange hawkweed (*Hieracium aurantiacum*), and

Kentucky bluegrass. At least 190 non-native plant species are known from Alaska, 125 species are listed as "Weeds to Watch" (Duffy et al, 2002), and 54 are currently tracked by the Alaska Exotic Plants Information Clearinghouse http://agdc.usgs.gov/akepic/, an interagency group that has posted maps and data for weed distributions. Mapping efforts have detected new locations with infestations of weeds known to cause problems in other areas, such as orange hawkweed, Canada thistle, and garlic mustard. Expanding development associated with ports, roads, and pipelines increases access to human activity and leaves behind disturbed ground that is vulnerable to invasion by non-native plant species (Hebert 2001). Disturbance processes, such as wildland fire and related treatments, may promote conditions for non-native plant establishment in boreal forest ecosystems (Harrod and Reichard 2001). The low frequency of any one plant is evidence that non-native plant invasions may still be in the early stages in many areas of Alaska. The Refuge System may have a unique opportunity to use predictive information on locations and habitats that are at risk to invasion so that populations of the worst invasive species can be eradicated early, before problems occur (Hebert 2001).

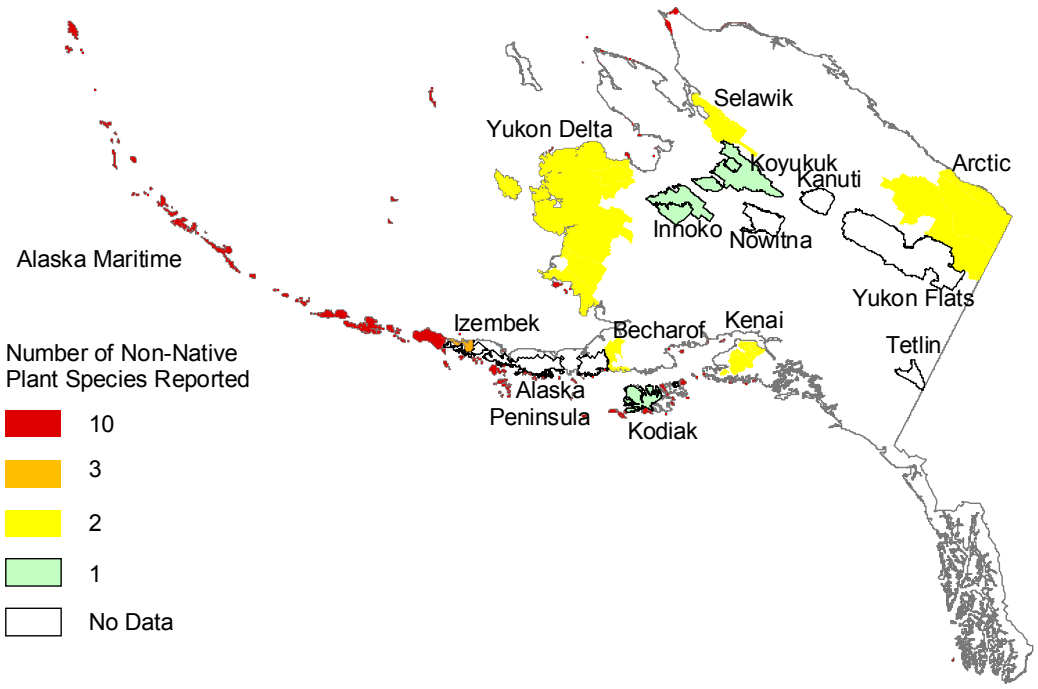


Figure 12. *The Refuge System in Alaska, with colors indicating the number of non-native plant species reported in recent surveys. Few species have been reported for most refuges in Alaska, but non-native plants have been introduced across the region.*

ACCESSIBLE AND USABLE INFORMATION

This report is simply an overview of the National Wildlife Refuge Invasive Species Survey. We report general findings and patterns, highlight some particularly damaging situations, and demonstrate how the Survey data might assist the Refuge System. The Survey is a powerful tool, but the static nature of this report limits the utility. Leveraging the technology of the internet to distribute the Invasive Species Survey information creates a dynamic means to exchange and access information and provides these benefits:

→The current status of invasive species at every refuge is available to Refuge System staff. Available information includes species lists, acreage and abundance estimates, control techniques and success rates, and the nature of inventory and monitoring programs.

→Managers can locate other refuges with similar invasive species problems. This will facilitate information exchange on particular invasive species, habitat vulnerability, and even coordination and cost sharing of control efforts.

→The information network will allow managers to identify landscapes and invasive species adjacent to their refuge and encourage the identification of source populations.

→National Wildlife Refuge scientists and coordinators have one place to view a national picture of the invasive species problem. Information can be used to identify gaps in data and provide a platform for the distribution of invasive species funding for inventory, monitoring, and control efforts.

→Each refuge is provided with a list of invasive species that occur around the refuge but not reported on the refuge. A refuge with an extensive invasive species program might use these lists to focus early detection efforts. A refuge with no information on invasive species might adopt the list as a potential baseline and proceed with appropriate inventory and control if needed.

→The collection of natural resource information and available datasets associated with each refuge will facilitate the needs of each refuge, but will also allow for the identification of datasets that will be essential for the development of predictive spatial models to describe the location of invasive species - Phase II.

The on-line tools can be found at www.nwrinvasives.com. The use of the internet will speed information exchange. Information needs to be shared, accessible, and move as fast, or faster than the spread of species if the invasion of the Refuge System network is to be halted.

APPLICATION OF THE INFORMATION TOOL – EXAMPLES

We present two examples that demonstrate how information acquired from the on-line database can be used to assist invasive species management decisions and target inventory, monitoring, and control efforts.

Control of Invasive Species on National Wildlife Refuges

The information obtained by this survey, and the tools of the web-based reporting system, will provide both perspective and technical information on control of invasive species. This can be illustrated by the invasion of melaleuca (*Melaleuca quinquenervia*) in Region 4 of the Refuge System. St. John's NWR reported a relatively small presence of melaleuca that mangers have not attempted to control. Melaleuca competes for water and minerals, often forming monocultures that displace native vegetation. The threat of this plant is serious enough to be recognized by federal and state noxious weed lists. Consideration of control presents a manager with a series of questions; the answers will be easily attainable from the Invasive Species Survey website.

- **Q:** Is the refuge vulnerable to more invasion?
- **A:** Besides the small infestation on the refuge, the Biota of North America Program data indicates that melaleuca is present in Brevard County, so a source population is likely in close proximity. This is confirmed by the report of melaleuca on Merritt Island NWR that shares Brevard County. Five other refuges in Florida reported melaleuca (Figure 13). Investigation of information collected in the Natural Resource section of the survey report suggests that St. John's NWR contains similar habitat types to these refuges. Especially common and vulnerable habitats in these refuges are the upland and wetland evergreen forests and perennial wet grass and forblands.
- **Q:** Might the St. John's NWR population of melaleuca serve as a source population for other areas?
- **A:** It may, and near by Merrit Island NWR controls melaleuca.
- **Q:** Do the ramifications of melaleuca spread justify control?
- **A:** Of the five other refuges in the state of Florida that reported melaleuca, all have spent time and money on control efforts.

If the funding is available and the information presented justifies control, more questions will arise that can be answered by the survey tools.

- **Q:** What techniques are other refuges using to control melaleuca and how well do they work?
- **A:** Many of the refuges use a combination of both mechanical and chemical treatments (Table 1). One might surmise that hand pulling is not enough to eradicate melaleuca as attempted at Ten Thousand Villages NWR. The reports from Florida Panther NWR indicate that pulling or mowing combined with treating the stumps (Arsenal) has been very effective for control. However, these techniques performed at Arthur Marshall Loxahatchee NWR

and Merritt Island were not as successful (Table 1). Further investigation of the survey responses explains the variance in success.

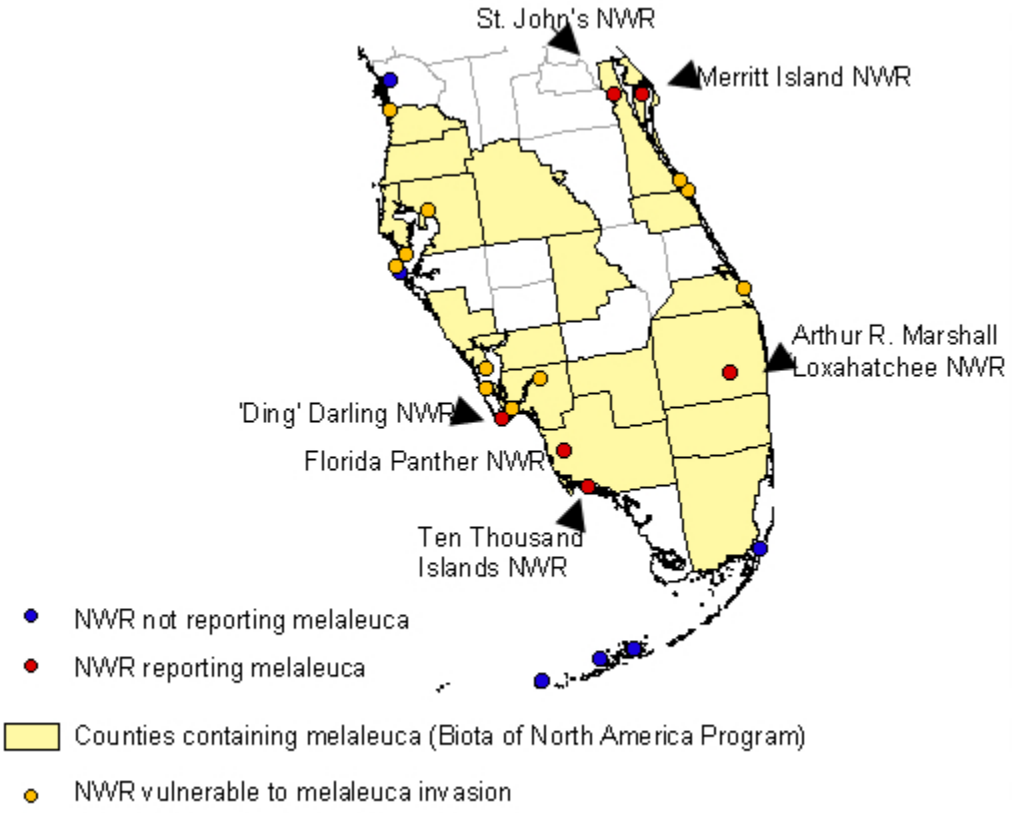


Figure 13. *Refuges invaded by and vulnerable to melaleuca in Florida.*

Table 1. Mechanical and chemical treatments used to control melaleuca (*Melaleuca quinquenervia*) at National Wildlife Refuges in Florida.

Refuge	Control	Mechanical	Efficacy	Chemical	Efficacy	Size (acres)
Ding Darling	Yes	Mow/cut	Excellent	Arsenal on cut stump	Excellent	19
St. John's	No			Garlon 4A spray seedlings	Good	62
Merritt Island	Yes	Hand pull mow/cut burn	Poor	Arsenal on cut stump	Excellent	7000
Florida Panther	Yes					2640
Ten Thousand Islands	Yes	Hand pull	Poor			3500
Arthur Marshall Loxahatchee	Yes			Not specified	Poor	89000

The infestations at both Merritt Island NWR and especially Arthur Marshall Loxahatchee are significantly larger than the other refuges controlling melaleuca (Table 1). The control or eradication of an invasive species, almost as a rule, is more effective or successful when the infestation is small for biological (more species means a constant new source) and economic (large populations of invasive species require lots of funding for staff and materials) reasons. The St. John's population is reported to be as small as 60 acres. The chance to control melaleuca before populations become unmanageable and more biologically significant may be enough justification to initiate a melaleuca control program. To get started, managers of St. John's can consult the information in this report and directly contact invasive species oriented personnel at Merritt Island NWR and other invaded refuges in Florida using the contact information that was collected by the survey. Practiced refuges could share nuances and pitfalls of melaleuca control, and inventory and monitoring techniques. It may be useful to share resources and personnel among refuges to control melaleuca and possibly other species. Regional directors could use the information complied from this survey to organize, fund, and direct such an infrastructure similar to the National Park Service swat teams. It may be that this crew could also search refuges immediately threatened by melaleuca invasion, thereby encouraging early detection efforts. Further analysis of county data suggests that 12 other refuges exist in counties that also contain melaleuca. Early detection will serve the refuge in question and other refuges and landscapes throughout the region.

Early Detection of Invasive Species in National Wildlife Refuges

The ability to provide managers with lists of invasive species that have invaded landscapes surrounding a refuge may be one of the most useful and effective tools resulting from this survey. Understanding what species might invade, and identifying the most vulnerable habitats, directs efficient and effective early detection and control efforts. These lists may serve as early detection lists for refuge managers with established invasive species programs, or they might function as the foundation of an invasive species program for a data-poor refuge. Either way, even the most basic and cursory inventory efforts could be made more efficient with the use of these lists.

Monomoy NWR occupies a small island off the coast of Cape Cod, in Barnstable county, Massachusetts. While the refuge acknowledges the presence of four non-native plant species, a biologist reports that invasive species have not been carefully inventoried or mapped, and invasive species are not being controlled. The Biota of North America Program lists 280 non-native plants in Barnstable County, many of these known to be problematic in Massachusetts (subset in Table 2). The Monomoy NWR habitat information reported in the Invasive Species Survey (Natural Resources section) can be compared to the habitats these species are likely to invade to determine vulnerability and to focus inventory efforts on both habitats and species. These targeted efforts will save time and money because fewer habitats need to be searched.

Table 2. Non-native plant species listed in Barnstable County, MA and vulnerable habitats at Monomoy NWR.

Species	Threat	Refuge Habitat (acres)
Tree of heaven (*Ailanthus altissima*)	Rapid growth allows for displacement of native vegetation, and released toxins prevent establishment of other natives.	Mud/Sand (1762)
Oriental bittersweet (*Celastrus orbiculatus)*	Overgrows native vegetation with vigorously growing vine that girdles and shades native species.	Mud/Sand (1762) Perennial upland grass (1000)
Japanese honeysuckle (*Lonicera japonica*)	Outcompetes native vegetation for resources above and below ground.	Deciduous upland shrub (138) Deciduous wetland shrub (200) Perennial upland grass (1000)
Jimsonweed (*Datura stramonium*)	Dense stands displaces native vegetation.	Mud/Sand (1762)
Japanese knotweed (*Fallopia japonica*)	Displaces native vegetation in edges of riparian and wetland habitats.	Deciduous wetland shrub (200)

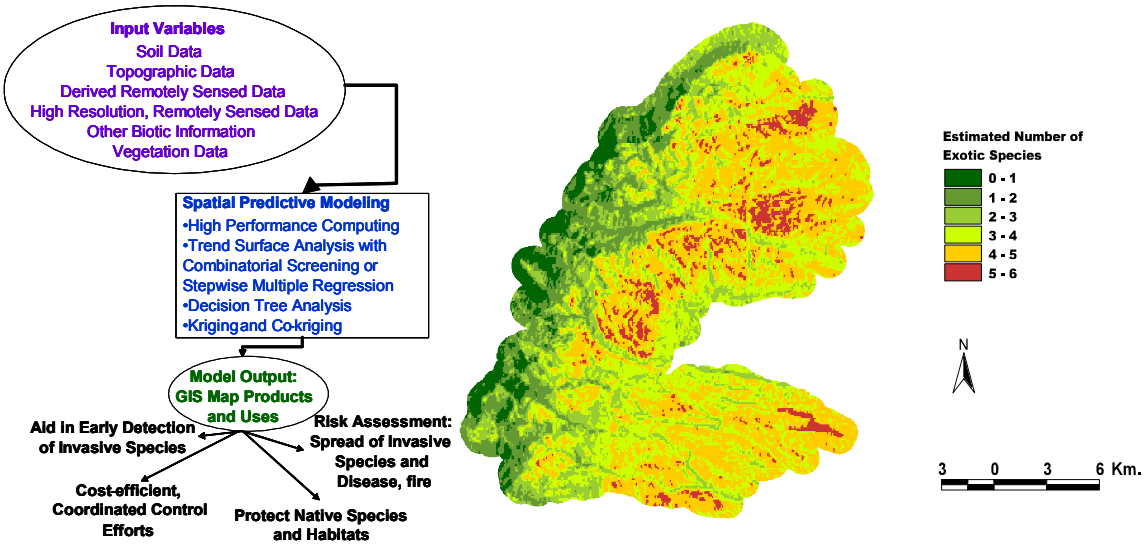
These lists act as a new suite of early detection inventory and monitoring tools. Vulnerable habitats can be targeted with specific search images. Simple flip-books with pictures and descriptions would allow refuge staff with limited botany skills to search, or casually look for invasive species during daily operations. These books could also be provided to volunteers concerned about the biological integrity of the refuge. The mobilization of many eyes and the development of identification tools will greatly enhance early detection efforts that are so crucial to prevention of invasive species establishment.

RECOMMENDATIONS FOR AN INVASIVE SPECIES MANAGEMENT PROGRAM: PHASE II

The information gathered from the Invasive Species Survey is best used to direct coordinated invasive species management programs throughout the Refuge System. A complete Invasive Species Management Program must contain elements of prevention, early detection (surveys), rapid response (containment), restoration, monitoring effectiveness of management actions, systematic data and information management, and research – in cooperation with other state and federal agencies, non-government organizations, and the public. These recommendations follow from the responses to the survey specifically to create a strategic and systematic approach to setting priorities for invasive species management in the Refuge System:

1. Maintain a complete and accurate system of information management. The system needs to be dynamic, allowing managers to enter information on occurrence, location, early detection, and the progress of control. The database needs careful maintenance and mechanisms for checking data accuracy and quality. To leverage the efforts of the National Wildlife Refuge System, this invasive species information management should be compatible with the US Geological Survey's Invasive Species Information Node of the National Biological Information Infrastructure. Data should be comparable to other ongoing efforts by states, land management agencies, non-government organizations, international efforts, and others.
2. Develop "early detection and rapid response" capabilities and work with cooperating agencies and others to quickly respond to new harmful invaders. New records of previously undetected invasive non-native plant species, non-indigenous animal species, or emerging diseases of plants or animals must be reported to control entities immediately.
3. Begin systematic surveys in those refuges with the least knowledge about invasive species and refuges determined to be highly vulnerable to invasion. In this case, a few rare/important habitats of special management concern are surveyed with volunteers, refuge staff, etc., with a subset of species and sites verified with a trained botanist, wildlife biologist, and disease expert with notes taken at specific sites, which are accurately located (GPS) and photographed (digital). For invasive plants, for example, field crews establish a few vegetation plots to quantify patterns of native and non-native species richness and cover and soil characteristics (see Stohlgren et al. 1997, 1998, 1999 for details, though these methods may be modified to improve sampling efficiency). See "Beyond NAWMA standards; www.NAWMA.org as a model approach for non-native plant invaders. For non-indigenous mammals, appropriate trapping and tracking techniques are used. For diseases, appropriate samples are collected and tested at a laboratory. Findings of several highly invasive species, many noxious species, or extensive outbreaks of any invasive species of management concern may require more rigorous surveys.
4. Escalate containment and control efforts in the most heavily invaded sites and habitats, and in both "source" populations and newly established satellite populations. Share control information, restoration approaches, and all trials and successes on the World Wide Web.
5. Work with others to model the current distributions of harmful invasive species, and the potential distributions and spread of invasive species (to and from Refuges in the System). Predictive spatial modeling displays the potential spread of targeted invasive species in the refuge and adjacent lands. The predictive models can be used to extrapolate information from the 1% of the land that can affordably be surveyed to the 99% of the unsampled landscape or populations in most refuges. The predictive models rely on species lists, datasets that include ancillary data, and other abiotic variables (Figure 14). These species lists and other sources of data should be identified by the survey process and the data clearing house. The models provide refuge managers and control entities with

information on known infestations, probable infestations, locations of vulnerable habitats and populations, and levels of uncertainty in model projections.



a. b.

Figure 14. *Predictive spatial models being cooperatively developed by Colorado State University, USGS, and NASA run a variety of statistical procedures on a variety of biotic and abiotic input variables to output a wide variety of tools useful to managers (a). For example, products can look like this map of the number of non-native plant species estimated to occur across a burned landscape near Los Alamos, N.M. (b).*

It is extremely important that a budget initiative be prepared to complete the appropriate level of surveys in all refuges. Part of the budget initiative will be to train USFWS staff, volunteers, and others to conduct future systematic, unbiased invasive species surveys, data management, and predictive modeling. This should include workshops and training sessions throughout the nation. A second major component of the budget initiative should be to develop basic resource information (inventories and high-resolution vegetation maps and wildlife population data for each refuge in the system). Basic information on natural resources is critical to plan effective control efforts while avoiding non-target effects to native plants and wildlife (Louda et al. 2003).

Coordination will be the backbone of this project. The primary benefit is that the Refuge System will be operating as a single unit in the efforts to deal with the invasive species problem. Behind habitat loss, invasive species are the leading cause of extinctions, and cost our country more than $137 billion/per year (www.invasivespecies.gov). This is a national issue. Coordinating this diverse network of wildlife refuges will not only help the mission of the system, but also make the Refuge System a leader in the management of invasive species.

LACREEK NATIONAL WILDLIFE REFUGE NON-NATIVE PLANT INVENTORY AND MAPPING: A PHASE II EXAMPLE

Pervasive non-native plant invasions at Lacreek NWR in South Dakota made this refuge an ideal location to test an "Objective 3"- type inventory. Refuge staff reported inventory, monitoring, and control on a suite of eight species. Control at Lacreek focuses primarily on Canada thistle; it invades all habitat types and wetter types in particular. Canada thistle presents problems for refuge management goals, and the refuge may be a regional source of the species to surrounding private landscapes (Sprenger, pers comm.). Furthermore, refuge staff acknowledged that other non-native plant species exist on the refuge as they track only species they have resources to control. Evaluation of non-native plant species in Bennett County suggested that Lacreek may contain, or be vulnerable to, invasion by many detrimental species: musk thistle (*Carduus nutans*), dalmatian toadflax (*Linaria dalmatica*), and yellow starthistle (*Centaurea solstitialis*) are just a few of the species on this list. These results, and available funding, qualified Lacreek as a high priority for extensive inventory and mapping of non-native plants species and testing of "Objective 3" protocols.

A combination of multi-scale plot sampling and testing of weed mapping techniques (see Beyond NAWMA, www.NAWMA.org) detected 27 non-native plant species at Lacreek NWR, 20 of these species were not on the refuge non-native species list. Current patterns of invasion and the makeup of the regional non-native species pool suggest that the mesic grassland, mesic woodland, forbland, upland grassland, and upland shrub habitat types are most vulnerable to invasion. Early detection efforts at Lacreek can focus on these vegetation types using the plot and mapping systems in conjunction with lists of probable invaders.

Invasive species ignore land management boundaries. Mitigating the spread of these species with prediction, early detection, and control must involve coordination across landscapes. The Invasive Species Survey and Phase II fieldwork provide a means for the Refuge System to address the invasive species problem with an organized and data rich system that coordinates refuges across the nation. The incorporation of regional datasets initiates collaboration with other agencies and Phase II perpetuates this trend. The multi-scale plot data is comparable to many data collection systems across the nation, including the National Forest Service Forest Inventory Analysis (FIA, previously Forest Health Monitoring). Implementation of the "Beyond NAWMA" mapping standards ensures that mapping efforts will be comparable to data collected by a multitude of organizations across the country and provides a means for distribution and data exchange. Phase II provides a mechanism for a iterative, nation-wide invasive species inventory effort that is an effective model of coordinated invasive species action within an agency and beyond.

CONCLUSIONS

The accelerated distribution of species around this planet is causing extensive harm to the native flora and fauna our Refuge System strives to maintain. The challenge these species present is ongoing and dynamic (Randall 2000); and ecological and economic costs will continue to grow (Pimentel et al. 2000). Recent history taught us

that our strictly reactionary approach to invasive species management is not cost-efficient. Regional and national-scale patterns of non-native plant invasions confirm that the most species-diverse, rare, and unique habitats are at risk (Stohlgren et al. 2001, Stohlgren et al. 2003). The best available information and a coordinated approach is needed to preempt invasions and contain problems before they become widespread epidemics. This Invasive Species Survey and subsequent research and management programs will take the Refuge System one step closer to this goal.

ACKNOWLEDGMENTS

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PEER REVIEW

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APPENDIX 1: The ten most frequently listed non-native plants (a), non-indigenous animals (b) and diseases of animals (c), and plants (d). Frequently reported species are in bold, but preliminary rankings may shift as we resolve ITIS taxonomic serial numbers.

a) Plants:

Scientific name (Number of Times listed)	Common name
Region 1 Pacific	
Cirsium arvense (28)	canada thistle
Phalaris arundinacea (23)	reed canary grass
Lepidium latifolium (20)	perennial pepperweed
Cytisus scoparius (18)	scotch broom
Tamarix ramosissima (16)	salt cedar
Centaurea solstitialis (14)	yellow starthistle
Lythrum salicaria (14)	purple loosestrife
Rubus discolor (13)	Himalayan blackberry
Xanthium strumarium (13)	cocklebur
Cirsium vulgare (12)	bull thistle
Region 2 Southwest	
Sapium sebiferum (7)	Chinese tallow tree
Tamarix aphylla/Tamarix sp. (6)	salt cedar
Cynodon dactylon (5)	Bermuda grass
Sorghum halepense (5)	Johnson grass
Tamarix ramosissima (4)	salt cedar
Arundo donax (3)	giant reed
Lonicera japonica (3)	Japanese honeysuckle
Melia azedarach (3)	Chinaberry
Salvinia molesta (3)	giant salvinia
Cenchrus ciliaris (2)	buffelgrass
Region 3 Midwest	
Alliaria petiolata (7)	garlic mustard
Cirsium arvense (6)	Canada thistle
Phalaris arundinacea (6)	reed canary grass
Bromus inermis (4)	smooth brome
Carduus nutans (4)	musk thistle
Lythrum salicaria (4)	purple loosestrife
Rosa multiflora (4)	multiflora rose
Euphorbia esula (3)	leafy spurge
Phragmites australis (3)	common reed
Poa pratensis (3)	Kentucky bluegrass
Region 4 Southwest	
Alternanthera philoxeroides (14)	alligator weed
Schinus terebinthifolius (10)	Brazilian pepper
Lonicera japonica (9)	Japanese honeysuckle
Sapium sebiferum (9)	Chinese tallow tree
Sorghum halepense (8)	Johnson grass
Hydrilla verticillata (5)	hydrilla
Phragmites australis (5)	common reed
Imperata cylindrical (4)	cogon grass

Lygodium japonicum (4)	Japanese climbing fern
Wisteria sinensis (4)	Chinese wisteria
Region 5 Northeast	
Phragmites australis (24)	common reed
Rosa multiflora (19)	multiflora rose
Lonicera japonica (17)	Japanese honeysuckle
Lythrum salicaria (13)	purple loosestrife
Cirsium arvense (12)	Canada thistle
Berberis thunbergii (11)	Japanese barberry
Celastrus orbiculatus (11)	Asiatic bittersweet
Polygonum cuspidatum (11)	Japanese knotweed
Elaeagnus umbellate (10)	autumn olive
Ailanthus altissima (8)	tree of heaven
Region 6 Mountain Prairie	
Cirsium arvense (17)	Canada thistle
Euphorbia esula (10)	leafy spurge
Carduus nutans (9)	musk thistle
Agropyron cristatum (7)	crested wheatgrass
Bromus inermis (7)	smooth brome
Elaeagnus angustifolia (6)	Russian olive
Poa pratensis (6)	Kentucky bluegrass
Artemisia absinthium (5)	wormwood sage
Juniperus virginiana (4)	eastern red cedar
Sonchus arvensis (4)	perennial sowthistle
Region 7 Alaska (3 surveys)	
Cirsium arvense (3)	Canada thistle
Cardaria draba (2)	hoary cress
Euphorbia esula (2)	leafy spurge
Artemisia absinthium (1)	wormwood sage
Brassica nigra (1)	black mustard
Bromus inermis (1)	smooth brome
Carduus nutans (1)	musk thistle
Centaurea maculosa (1)	spotted knapweed
Collomia linearis (1)	mountain trumpet
Hieracium aurantiacum L. (1)	orange hawkweed
Poa pratensis (1)	Kentucky bluegrass
All Regions 1-7	
Cirsium arvense (63)	Canada thistle
Phragmites australis (42)	common reed
Phalaris arundinacea (36)	reed canary grass
Lythrum salicaria (35)	purple loosestrife
Lonicera japonica (30)	Japanese honeysuckle
Rosa multiflora (24)	multiflora rose
Sorghum halepense (23)	Johnson grass
Tamarix ramosissima (22)	salt cedar
Lepidium latifolium (21)	perrenial pepperweed
Elaeagnus angustifolia (20)	Russian olive

b) Animals:

Scientific name (Number of times listed)	Common Name
Region 1 Pacific	
Rana catesbeiana (26)	American bullfrog
Sturnus vulgaris (20)	European starling
Cyprinus carpio (18)	common carp
Myocastor coypus (11)	nutria, coypu
Felis catus (8)	domestic cat
Molothrus ater (7)	brown-headed cowbird
Mus musculus (6)	house mouse
Passer domesticus (6)	house sparrow
Lepomis (5)	sunfish spp.
Branta canadensis moffitti (4)	western Canada goose
Region 2 Southwest	
Sus scrofa (11)	feral hog
Gambusia affinis (3)	western mosquitofish
Myocastor coypus (3)	nutria, coypu
Passer domesticus (3)	house sparrow
Rana catesbeiana (3)	American bullfrog
Sturnus vulgaris (3)	European starling
Cyprinus carpio (2)	common carp
Equus asinus (2)	donkey
Felis catus (2)	domestic cat
Hemidactylus turcicus (2)	Mediterranean gecko
Region 3 Midwest	
Cyprinus carpio (9)	common carp
Sturnus vulgaris (5)	European starling
Dreissena polymorpha (3)	zebra mussel
Hypophthalmichthys nobilis (2)	bighead carp
Morone Americana (2)	white perch
Neogobius melanostomus (2)	round goby
Passer domesticus (2)	house sparrow
Alosa pseudoharengus (1)	alewife
Carassius auratus (1)	goldfish
Carpodacus mexicanus (1)	house finch (expanding range)
Region 4 Southeast	
Myocastor coypus (13)	nutria, coypu
Sus scrofa (13)	feral hog
Solenopsis wagneri (12)	red imported fire ant (=S. invicta)
Canis latrans (5)	coyote (expanding range)
Dasypus novemcinctus (5)	nine-banded armadillo
Sturnus vulgaris (5)	European starling
Anolis sagrei (3)	brown anole
Felis catus (3)	domestic cat
Osteopilus septentrionalis (3)	Cuban tree frog
Astronotus ocellatus (2)	oscar cichlid

Region 5 Northeast

Sturnus vulgaris (13)	European starling
Cygnus olor (12)	mute swan
Passer domesticus (11)	house sparrow
Cyprinus carpio (8)	common carp
Columba livia (5)	rock dove, feral pigeon
Phasianus colchicus (5)	ring-necked pheasant
Canis latrans (4)	coyote (expanding range)
Micropterus salmoides (4)	largemouth bass
Carassius auratus (3)	goldfish
Carpodacus mexicanus (3)	house finch (expanding range)

Region 6 Mountain Prairie

Phasianus colchicus (9)	ring-necked pheasant
Cyprinus carpio (5)	common carp
Passer domesticus (5)	house sparrow
Sturnus vulgaris (5)	European starling
Perdix perdix (4)	grey partridge
Rana catesbeiana (2)	American bullfrog
Alectoris chukar (1)	chukar partridge
Columba livia (1)	rock dove, feral pigeon
Ctenopharyngodon idella (1)	grass carp
Cyprinella spiloptera (1)	spotfin shiner

Region 7 Alaska

Alopex lagopus (1)	arctic fox
Bos taurus (1)	cattle
Lemmus (1)	lemmings
Lepus americanus (1)	snowshoe hare
Marmota caligata (1)	hoary marmot
Microtus (1)	voles
Oryctolagus cuniculus (1)	domestic rabbit
Rangifer tarandus (1)	caribou, reindeer
Rattus norvegicus (1)	Norway rat
Spermophilus parryii (1)	arctic ground squirrel

All Regions 1-7

Sturnus vulgaris (51)	European starling
Cyprinus carpio (43)	common carp
Rana catesbeiana (34)	American bullfrog
Passer domesticus (29)	house sparrow
Myocastor coypus (28)	nutria, coypu
Sus scrofa (26)	feral hog
Phasianus colchicus (15)	ring-necked pheasant
Felis catus (14)	domestic cat
Solenopsis wagneri (14)	red imported fire ant
Cygnus olor	mute swan

c) Animal Disease

Scientific name (Number of times listed)	Common Name
Region 1	
Clostridium botulinum (6)	avian botulism
Neosartorya (5)	Aspergillus spp.
Pasturella multocida (3)	avian cholera
Brucella (1)	brucellosis
distemper, feline (1)	distemper
Erysepelis (1)	
Francisella tularemsis (1)	tularemia; cutaneous fibromas
Parelaphostongylus (1)	hair-loss syndrome
Plasmodium (1)	avian malaria
Poxvirus avum (1)	avian poxvirus
Region 2	
alcelaphine herpesvirus-1 (AHV-1) (1)	malignant catarrhal fever
Demodex odocoilei (1)	demodectic mange
Fibroma papilloma (1)	cutaneous fibroma
Pasturella multocida (1)	avian cholera
Sarcoptes scabei (1)	scabies
Region 3	
Francisella tularemsis (2)	tularemia; cutaneous fibromas
Clostridium botulinum (2)	avian botulism
Epizootic hemorrhagic disease (EHD) (1)	epizootic hemorrhagic disease (EHD)
Flavivirus (1)	West Nile virus
Pasturella multocida (1)	avian cholera
Sarcoptes scabiei	sarcoptic mange
Region 4	
Epizootic hemorrhagic disease (EHD) (4)	epizootic hemorrhagic disease (EHD)
Distemper, zoonotic (3)	distemper
Trichothecenes (2)	mycotoxiosis
Pseudorabies (2)	pseudorabies
Borrelia burgdorferi (1)	lyme disease
Brucella (1)	brucellosis
Fibropapillomatosis (1)	Green turtle fibropapilloma
Flavivirus (1)	West Nile virus
Haemonchus contortus (1)	large stomach worm
lead toxicosis (1)	lead poisoning
Leptospira interrogans (1)	leptospirosis
Mycobacterium tuberculosis (1)	tuberculosis
Mycoplasma URTD (1)	upper respiratory tract disease (URTD)
Neosartorya (1)	Aspergillus spp.
Region 5	
Flavivirus (6)	West Nile virus
Borrelia burgdorferi (1)	lyme disease
Clostridium botulinum (1)	avian botulism
duck viral enteritis	duck plague
epizootic hemorrhagic disease (EHD) (1)	epizootic hemorrhagic disease (EHD)
Region 6	
Clostridium botulinum (4)	avian botulism
Histomonas meleagridis (1)	blackhead disease (turkeys)
Pasturella multocida (1)	avian cholera
Chlamydia psittaci (1)	chlamydiosis

epizootic hemorrhagic disease (EHD) (1)	epizootic hemorrhagic disease (EHD)
Region 7	
Toxoplasma gondii (1)	canicola
Leptospira interrogans (1)	leptospirosis
Regions 1-7	
Clostridium botulinum (13)	avian botulism (all types)
Flavivirus (8)	West Nile virus
epizootic hemorrhagic disease (EHD) (7)	epizootic hemorrhagic disease (EHD)
Neosartorya (6)	Aspergillus spp.
Pasturella multocida (5)	avian cholera
Francisella tularemsis (3)	tularemia
distemper, zoonotic (3)	distemper
Brucella (2)	brucellosis
Borrelia burgdorferi (2)	lyme disease
Leptospira interrogans (2)	leptospirosis
Trichothecenes (2)	mycotoxiosis
Toxoplasma gondii (2)	canicola

d) Plant Disease: *Insect plant pests were typically reported as non-indigenous animals.

Scientific name (Number of times listed)	Common Name
Region 1	
Cronartium ribicolae (1)	white pine blister rust
Tetranichidae (1)	spider mites
Homoptera (1)	scale
Cydia succedana (1)	gorse pod moth
Apion ulicis (1)	gorse seed weevil
Agonopterix ulicitella (1)	gorse soft shoot moth
Region 2	
Ceratocystis fagacerum (1)	oak wilt fungus
Region 4	
Ceratostomella ulmi (2)	Dutch elm disease
Dendroctonus frontalis (1)	southern pine beetle
Region 5	
Ceratostomella ulmi (3)	Dutch elm disease
Region 6	
Ceratostomella ulmi (1)	Dutch elm disease
Regions 1-7	
Ceratostomella ulmi (6)	Dutch elm disease
Cydia succedana (1)	gorse pod moth
Apion ulicis (1)	gorse seed weevil
Agonopterix ulicitella (1)	gorse soft shoot moth
Ceratocystis fagacerum (1)	oak wilt fungus
Cronartium ribicolae (1)	white pine blister rust
Homoptera (1)	scale
Dendroctonus frontalis (1)	southern pine beetle
Tetranichidae (1)	spider mites