National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Invasive Animals in U.S. National Parks

By a Science Panel

Natural Resource Report NPS/NRSS/BRD/NRR—2017/1564

ON THE COVER
Feral Hog, NPS Photo.

Invasive Animals in U.S. National Parks
By a Science Panel

Natural Resource Report NPS/NRSS/BRD/NRR—2017/1564

Primary Author(s): Kent H. Redford[1], Karl Campbell[2], Ashley Dayer[3], Chris Dickman[4], Rebecca Epanchin-Niell[5], Ted Grosholz[6], Dave Hallac[7], Leslie Richardson[8], Mark Schwartz[9]

[1]Archipelago Consulting
Portland, ME

[2]Island Conservation
Galápagos Islands, Ecuador

[3] Department of Fish & Wildlife Conservation
Virginia Tech, VA

[4]The University of Sydney
Sydney, Australia

[5]Resources for the Future
Washington, D.C.

[6]Department of Environmental Science & Policy
University of California
Davis, CA

[7]National Park Service
Cape Hatteras National Seashore and the Outer Banks Group
Manteo, NC

[8] National Park Service
Environmental Quality Division
Fort Collins, CO

[9]Department of Environmental Science & Policy
University of California
Davis, CA

December 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

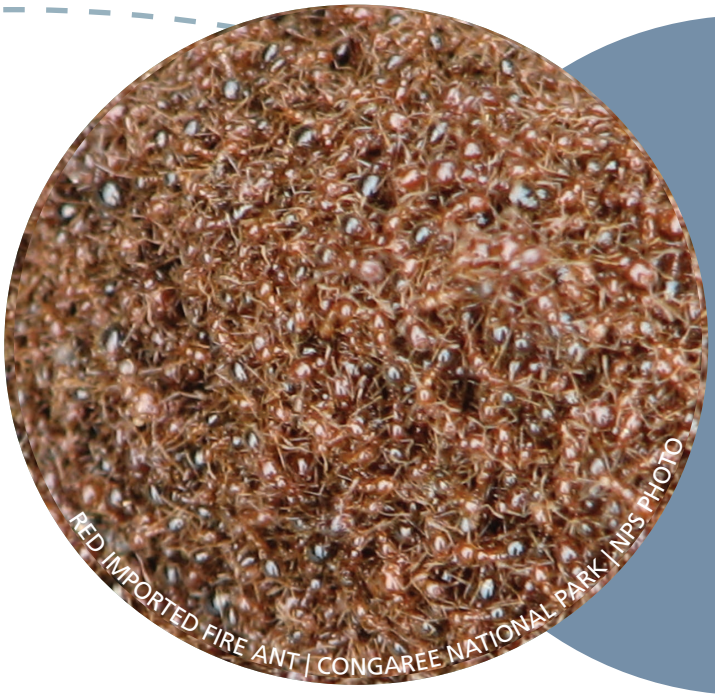
Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the Biological Resources Division website, and the Natural Resource Publications Management Website on the Internet. To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:
Redford, Kent H., K. Campbell, A. Dayer, C. Dickman, R. Epanchin-Niell, T. Grosholz, D. Hallac, L. Richardson, M. Schwartz. 2017. Invasive animals in U. S. national parks: By a science panel. Natural Resource Report NPS/NRSS/BRD/NRR—2017/1564. National Park Service, Fort Collins, Colorado.

NPS 909/141360, December 2017

Contents



RED IMPORTED FIRE ANT | CONGAREE NATIONAL PARK | NPS PHOTO

Key Message

Our nation's national parks are managed to preserve unimpaired America's natural and cultural resources. This mission is under a deep and immediate threat as a consequence of invasive animal species, yet the National Park Service does not have a comprehensive understanding of the costs and impacts of invasive animals or a coordinated strategy for their management. Despite these challenges, there are bright spots where parks are managing invasive species challenges, as well as opportunities for the National Park Service to take a lead in addressing the threat. Successfully maintaining the nationally and globally significant values of the National Park System will require coordinated and innovative action to manage invasive animal species.

Executive Summary

The national parks of the United States of America are a national and global treasure. They conserve natural and cultural resources that are an irreplaceable part of the national fabric. Unfortunately, they are also under threat on a variety of fronts including invasive animals. Over half of all U.S. national parks report the presence of invasive animal species from freshwater mussels to feral cats. The National Invasive Species Council (NISC) defines invasive species as those that are: "1) non-native (or alien) to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health." The threat caused by invasive animals has long been acknowledged by the National Park Service (NPS). There have been park-specific actions taken, some highly effective, but overall there has been no strategic, coordinated servicewide action taken in regards to invasive animals.

Of nearly 1,500 reported populations of invasive animals in national parks, only a small percentage can be considered under some form of management, be it eradication, containment, or control. Further, these invasive populations are demonstrably obstructing national parks from fulfilling their mission. This trend is expected to not only continue, but to increase when accelerated by other growing impacts such as fragmentation, climate change, and other environmental changes. Despite wide-ranging impacts from invasive animals that affect almost every NPS unit with land and water to manage, NPS has not yet developed a servicewide organizational approach for their management.[i] A piecemeal approach needs to be replaced with a strategic approach to effectively manage invasive species within parks or in collaboration with conservation partners on adjacent lands or waters and across the greater landscape.

In 2017, commissioned by the NPS Chief of Biological Resources Division (BRD) of the National Park Service, the NPS convened a Science Panel (Panel) to evaluate the extent of the problem of invasive animal species, assess management needs, review best practices, and assess potential organizational models that could serve as a servicewide organizational framework. The Panel (appendix A) was requested to pay particular attention to innovative and creative approaches including, but not limited to, new genomic tools.

Meeting through the first half of 2017, the Panel report is based on a variety of inputs including an extensive literature search, the experience of the Panel members, a series of commissioned presentations prior to the 2017 George Wright Society meetings (appendix B), and a report commissioned by BRD, Invasive Animals in the National Park Service: Biodiversity Under Siege Report. The latter report is based on information collected from NPS units under the terms of the Government Performance and Results Act which summarizes data from 327 of the 404 parks queried. Data from this document were supplemented by a set of case studies solicited from individual parks and data provided by BRD.

The Panel identified six key findings, each with a set of specific findings. These are listed below and discussed in detail in the body of the report.

What is NISC?

NATIONAL INVASIVE SPECIES COUNCIL
SECRETARIAT

On February 3, 1999, Executive Order 13112 (updated in Executive Order 13751 on December 5, 2016) established the National Invasive Species Council (NISC or Council) to "provide national leadership regarding invasive species." Council membership resides with the highest level Federal executives.

The overarching duty of the Council is to provide the high-level vision and leadership necessary to sustain and expand Federal efforts to safeguard interests of the United States by preventing, eradicating, and controlling invasive species, as well as restoring ecosystems and other assets impacted by invasive species. NISC's policy and planning activities benefit from the technical input provided by Federal agency staff and Federal inter-agency bodies working on invasive species issues, as well as non-Federal stakeholders.

The Federal Government defines invasive species to mean, with regard to a particular ecosystem, a non-native organism whose introduction causes, or is likely to cause, economic or environmental harm, or harm to human, animal, or plant health.
—executive order 13751

doi.gov/invasivespecies

Key Findings

Key Finding 1. Invasive animals pose a significant threat to the cultural and natural values and the infrastructure of U.S. national parks. To date, the NPS has not effectively addressed the threat they pose.

☐ Specific Finding 1a. Invasive animals are a global and national issue.
☐ Specific Finding 1b. Invasive animals are creating significant widespread problems for the NPS.
☐ Specific Finding 1c. The NPS currently lacks a comprehensive understanding of the impacts of invasive animals and the cost of appropriate effective invasive species management.
☐ Specific Finding 1d. Management efforts by the NPS to date have been largely piecemeal, poorly coordinated, and severely under-funded.

Key Finding 2. Managing invasive animals will require action starting at the highest levels, engaging all levels of NPS management, and will require changes in NPS culture and capacity.

☐ Specific Finding 2a. Coordinating efforts across the NPS for effective invasive animal management is a challenge that NPS can meet, but it will require changes in NPS organization, culture, and capacity.
☐ Specific Finding 2b. The NPS can be organized to provide effective management of invasive animals.

Key Finding 3. Prevention, eradication, containment, and control of invasive animals cannot be addressed by individual parks themselves, but require proactive coordinated institutional action amongst multiple land managers at the land and seascape scale.

☐ Specific Finding 3a. Invasive species are not constrained by jurisdictional boundaries.
☐ Specific Finding 3b. Cross-boundary action is required to manage invasive animals.
☐ Specific Finding 3c. Proactive management is a vital part of invasive animal management.
☐ Specific Finding 3d. To effectively manage the breadth and impact of invasive animals, the NPS will need to invest much more heavily in partnerships with other federal, state, and local agencies and organizations.

Key Finding 4. Effective management of invasive animals will require stakeholder engagement, education, and behavior change.

☐ Specific Finding 4a. Gaining public support for broader management goals and management actions is essential for successful management.
☐ Specific Finding 4b. Stakeholder engagement through participatory approaches is needed to gain 'social license' for effective invasive animal management and to minimize conflict.
☐ Specific Finding 4c. Changing human behavior is a key part of achieving active support for invasive animal management.
☐ Specific Finding 4d. Engaging the public through community science can contribute to effective management.
☐ Specific Finding 4e. The NPS is well-poised, as a consequence of their substantial investment in education and interpretation, to develop effective public engagement on the issue of invasive species, but doing so will require national leadership.

Key Finding 5. The NPS has the opportunity to address invasive animal management through emerging best practices in structured decision support for natural resource management.

☐ Specific Finding 5a. Developing the capacity for the NPS to organize resource management using decision frameworks will increase the potential for realizing a future state of effective invasive animal management.
☐ Specific Finding 5b. Effective invasive animal management will require changes in management.
☐ Specific Finding 5c. Effective invasive animal management will require increases in or redirection of funding.

Key Finding 6. The NPS can become a major actor in developing, testing, and deploying new technologies and approaches.

☐ Specific Finding 6a. Successful management of invasive animals will require programs for information management and effectiveness monitoring.
☐ Specific Finding 6b. Innovation holds great promise for moving the NPS towards the efficient and effective management of invasive animals.

Introduction

The U.S. National Park Service (NPS) manages 417 national park units, located in every one of the 50 states and many U.S. territories and encompassing over 84 million acres. From American Samoa to Guam, the northernmost reaches of Alaska, southwestern deserts, and the Virgin Islands, national parks protect some of the nation's most important ecosystems, native iconic plant and animal species, cultural resources, and the stories and values that define America.

The mission of the NPS is to: "preserve unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations." This can be challenging to implement given the many human-caused stressors and conflicting interests of stakeholders. Surrounded by development and adjacent land management agencies with different missions, species and ecosystems found in parks may be affected by many kinds of alterations including those to migration corridors, water utilization and hydrologic management practices, and unnatural fire regimes. One of the major stressors that challenge park managers' ability to carry out the NPS mission are invasive animals. The National Invasive Species Council (NISC) defines invasive species as those that are: "1) non-native (or alien) to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health." The threat caused by invasive animals has long been acknowledged by the NPS, but it is time for NPS to recognize that this threat is as significant as any challenge facing the park system and of immediate and widespread concern.

Burmese Python, NPS Photo.

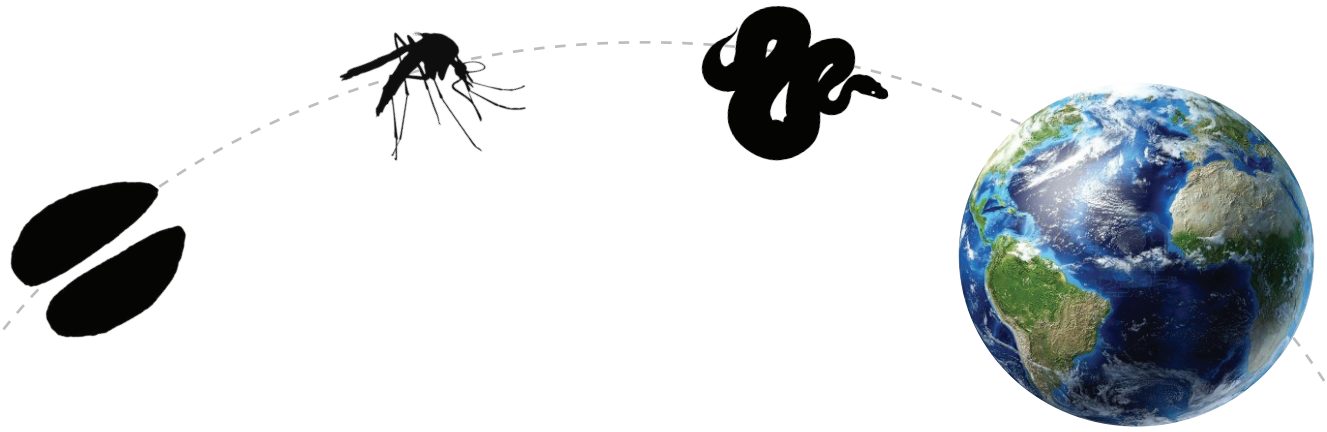
The NPS developed an invasive plant program in 2000 out of the guidance provided by the Natural Resource Challenge, but did not take a strategic look at the management challenges posed by invasive animals although the direction was to address "invasive species" across the service. In order to remedy this, in 2017, through its Chief of BRD, NPS convened a Science Panel (Panel) to evaluate the extent of the problem of invasive animal species, assess management needs, review best practices, and assess potential organizational models that could serve as a servicewide organizational framework. The Panel was requested to pay particular attention to innovative and creative approaches including, but not limited to, new genomic tools.

Science Panel

The Panel was chaired by Dr. Kent H. Redford and included representatives from government, academia, and the non-government sector. A variety of disciplinary perspectives was represented including economics, human dimensions of wildlife, ecology, conservation biology, park management, invasive species management, and policy. The majority of members were from the U.S. with members also from Ecuador and Australia (appendix A for panel members, names, institutions). NPS expertise was incorporated through the inclusion of a resource economist and park superintendent on the Panel and the involvement of three senior NPS staff during the George Wright Society meeting.

The Panel met virtually three times before April 2017, when the group convened at the George Wright Society meeting in Norfolk, Virginia. At the meeting, it met on its own and ran two sessions to solicit the input of the meeting participants. Three additional virtual meetings accompanied the completion of the Panel's report.

This report is based on a variety of inputs including an extensive literature search, the experience of the Panel members, a series of commissioned presentations held adjacent to the 2017 George Wright Society meetings (appendix B), and a report commissioned from the NPS Chief of the Biological Resource Division titled Invasive Animals in the National Park Service: Biodiversity Under Siege Report. The latter report is based on information collected from NPS units under the terms of the Government Performance and Results Act which summarize data from 327 of the 404 parks queried. Data from this document were supplemented by a set of case studies solicited from individual parks and data provided by BRD.



Key Findings

The report is structured around six Key Findings, each of which has a set of Specific Findings. Each Specific Finding is supported by a discussion of the relevant literature and NPS findings.

Key Finding 1. Invasive animals pose a significant threat to the cultural and natural values and the infrastructure of U.S. national parks. To date, the NPS has not effectively addressed the threat they pose.

☐ Specific Finding 1a. Invasive animals are a global and national issue.

Recent estimates indicate that invasive species negatively affect almost 2,300 threatened or near-threatened species worldwide (26.5% of all species that have been adequately assessed), and have contributed to the extinction of many others.[iii] Although habitat loss and direct over-exploitation by people affect more species, these threats usually stop at park boundaries whereas those posed by invasive species do not. The problems caused by invasive animals extend well beyond their effects on native species, and include disruption to important habitats, communities, and ecosystem services that together increase stress on the natural environment. Invasive rats, for example, have caused the extinction of endemic island birds throughout the Pacific, while feral hogs continue to wreak havoc on habitat structure and populations of birds and other small vertebrates in many parts of the world. Free-ranging domestic cats kill over a billion birds a year in the U.S.[iv]

The global economic impacts caused by invasive species are difficult to assess accurately, although several studies have attempted to quantify damage costs at national or multinational scales. According to Pimentel et al. (2001), for instance, species invasions in the United States, United Kingdom, Australia, South Africa, India, and Brazil cause around $336 billion per year in damages, with invasive animals accounting for more than 40% of this cost. Assuming similar costs worldwide, they predict that damages from invasive species could total more than $1.4 trillion per year. The authors do note that precise costs associated with some of the most ecologically damaging species, such as cats and pigs, were not available, and if monetary values could be assigned to species extinctions, losses in biodiversity, ecosystem services, and aesthetics, the costs of invasive species would be several times higher. A recent study puts the cost of invasive insects alone at approximately $27 billion per year in North America.[v] An updated study by Pimentel et al. (2005) estimates annual economic and environmental losses from invasive species in the U.S. to be $120 billion, nearly half of which is attributed to invasive animals. Mammals and birds alone cause around $46 billion in damage and control costs each year.[vi] These studies provide some of the more comprehensive estimates of the economic impacts of invasive species, but have been criticized for assuming fixed prices and failing to account for possible adjustments of economic behavior to changing market conditions from harmful invasive species.[vii] Despite these shortcomings, it seems clear that invasive animals have significant economic impacts throughout the world.

Table 1. Park response to 2016 data call.

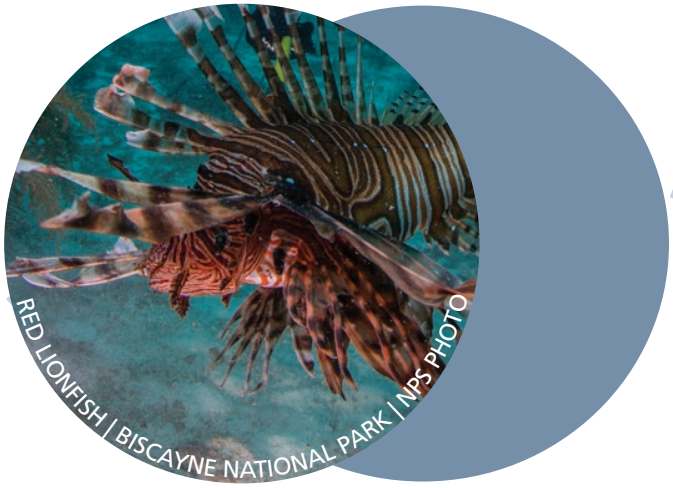
Questions in the data call	NPS Total	Alaska Region	Inter-moun-tain Region	Mid-west Region	National Capital Region	North-east Region	Pacific West Region	South-east Region
Representativeness of Data Call								
# parks queried in data call	404	16	83	53	42	83	65	62
Response Rate								
% parks responding	81%	100%	99%	70%	29%	80%	78%	100%
Occurrence								
# species reported	331	5	107	53	19	70	151	94
# park populations reported	1409	6	355	161	59	202	337	289
% parks reporting at least one species	68%	25%	75%	62%	44%	68%	66%	89%

In addition to economic costs invasive animals can also have pervasive impacts on human society through effects on public health, ecosystem services, and cultural dimensions. Invasive animals such as mosquitoes can carry invasive diseases that affect human health, zebra mussels can diminish freshwater services, and declines and extinctions of native birds in Hawai'i due to the spread of avian malaria and avian poxvirus[viii] have removed them from the cultural traditions of local people and decreased public connection to the land.

☐ Specific Finding 1b. Invasive animals are creating significant widespread problems for the NPS.

According to the information collected from parks (Table 1) in the NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report, 245 parks (of 326 that responded) report at least one invasive animal species occurring inside the park. This results in 1,409 reported invasive animal populations occurring in parks distributed across 331 species. Despite this large number of populations, parks report just 327 populations for which management plans have been developed (43 more if adjacent or eradicated populations are included), 384 with expenditures (44 more if adjacent and eradicated populations are included) in an effort to control populations and 150 populations where control has been achieved (17 more if eradicated populations are included). Parks report that for 21 invasive animal populations, eradication was attempted in 2016 or earlier, with the majority (17) of those populations still under control in 2016. Many of these eradication attempts occurred in the Pacific West region (9 populations eradicated, 8 of which are still under control) and Southeast region (8 populations eradicated, 6 of which are still under control). The Intermountain, Northeast, and National Capital regions each have reported one invasive animal population eradicated and under control. The number of invasive animal populations reported by parks must be considered an underestimate as limited staffing and budget do not allow for comprehensive reporting. A handful of well-known invasive species make up the majority of what was reported by parks which suggests that there may be many other species that have either not been detected or not reported. There further appears to be a bias in reporting towards vertebrates relative to invertebrates which may be due to the greater ability to detect and identify vertebrates.

Although these successful eradications are promising, it is important to note that expenditures are often needed to maintain an eradication. For example, even after a species has been removed from park boundaries, infrastructure such as fencing and follow up monitoring may be needed to prevent their return. Indeed, parks report that 43% (9 of 21) of previously eradicated invasive animal populations require continued investment to prevent reinvasion. Though clearly not eradicated, one of the few examples of the economic costs of invasive animal control comes from Everglades National Park where 10 years of control of snakes cost more than $5.5 million and has been markedly unsuccessful.[ix]

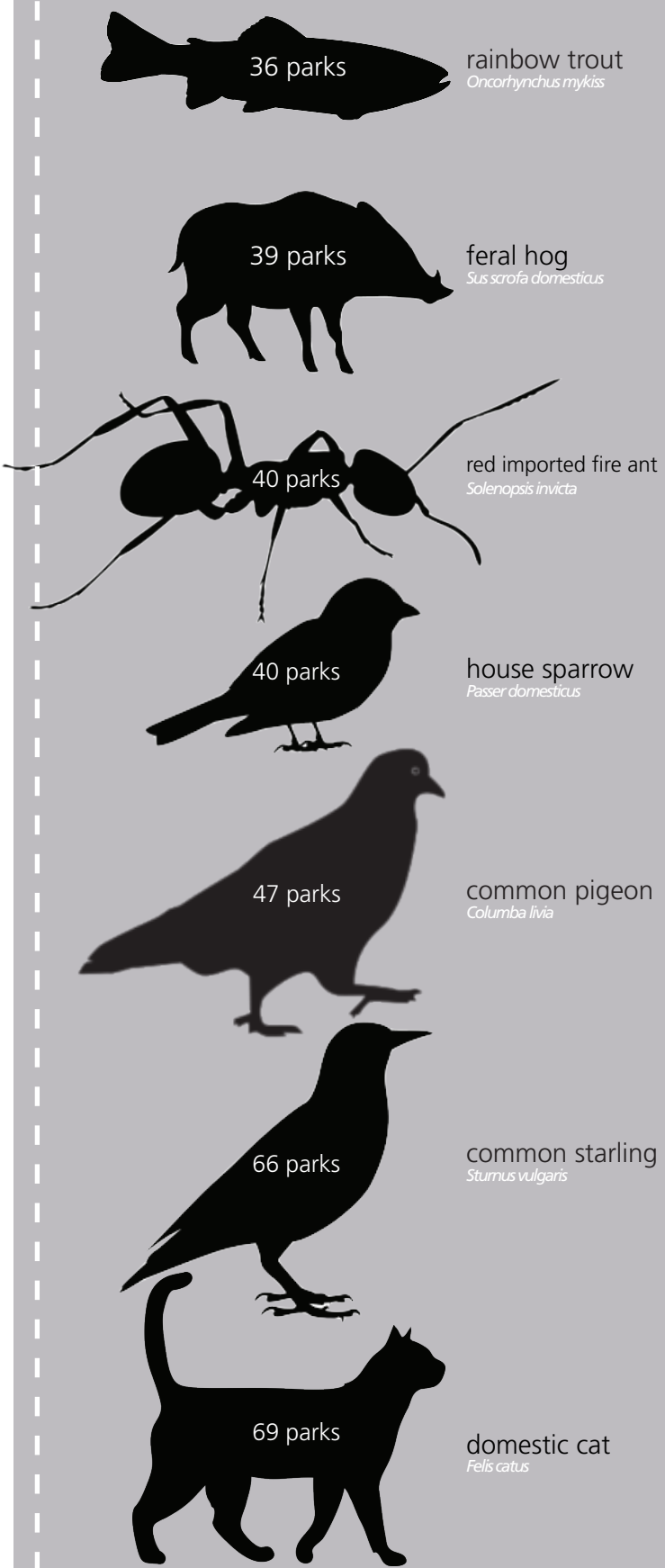


Invasive animals are not a new problem, and in its early years the NPS contributed to what has become today's problem through deliberate introductions of non-native species in parks.[x] When the NPS conducted a survey in 1977, 155 parks already

Table 2. Impacts to parks from invasive animals.[xii]

Type of Impact	Description of Impacts	Species Examples	Affected National Park
Impacts on Native Species	Loss of native plants and animals	Feral swine	Great Smoky Mountains NP
		Nutria	Big Bend NP, Jean Lafitte NHP
	Loss of sensitive species, local or regional extinction	Lionfish	Biscayne NP, Virgin Islands NP
		Burmese python	Everglades NP
Impacts on Communities and Ecosystems	Loss of habitat, changes in nutrient cycling, erosion	Quagga and zebra mussels	Great Lakes NPs
		Feral swine	Hawaiian NPs
		Lionfish	Biscayne NP, Virgin Islands NP
	Reductions at lower trophic levels, community changes	Burros	Grand Canyon NP
		Rainbow trout	Yosemite NP
Disease Vectors	Promote spread of infectious diseases of wildlife and humans	Mosquitoes (avian malaria)	Hawaii Volcanoes NP
		Brown trout (whirling disease)	Yellowstone NP
Hybridization	Loss of native gene pool Possible loss of native species	Africanized honey bees, natives	Saguaro NP
		Rainbow trout, native trout	Glacier NP
Human Recreation	Restrict access, ruin recreational benefits	Quagga and zebra mussels	Great Lakes NPs
		Feral swine	Great Smoky Mountains NP
Human Health	Vector for diseases Impact safety and health	Mosquitoes	Southern NPs
		Africanized bees	Everglades NP, Saguaro NP
Cultural Impacts	Damage to significant archaeological sites, structures, and landscapes	Feral swine	Hawaii Volcanoes NP, Channel Island NP

most common INVASIVE ANIMALS in national parks



reported the presence of one or more exotic vertebrate species, and exotic animals were the fourth most commonly reported source of threats. In 1991, parks had identified 200 unfunded projects to address exotic species, costing almost $30 million.[xi]

Invasive animal species arrive in parks in one of three possible ways: 1) intentional releases; 2) unintentional releases; and 3) range shifts - often as the result of changes in resource availability, land use, climate, etc. [xiii] Each of these three modalities is influenced by one of several motivations and have their own impacts on park resources.

Invasive species can have a broad range of impacts that have been well documented and summarized[xiv] and have effects in parks (Table 2).

The recreational experiences of park visitors also are influenced by invasive animals which threaten park infrastructure, disrupt ecological processes, threaten visitor well-being, degrade cultural resources, and potentially interfere with visitor experiences. Hunting, fishing, hiking, boating, birding, and other outdoor recreation have all been negatively affected by invasive animals, including tree death from emerald ash borer and woolly adelgid invasions that threaten visitor safety from falling trees. Impacts can be the result of indirect effects of animals that include trampling, overgrazing, and disturbance. Also, large introduced animals like feral swine can restrict human usage in certain areas. Other invasions can affect hunting and fishing and other recreational opportunities. Though caused by an invasive disease organism, not an animal, the rapid and extensive impact of the fungal pathogen 'rapid 'ohi'a death' is killing hundreds of thousands of 'ohi'a trees in Hawaii, including in Hawai'i Volcanoes National Park[xv], compromising ecosystem integrity and visitor experience as well as potentially causing harm to visitors.

Invasive animals can also substantially and negatively impact human infrastructure within the National Park System. These types of impacts are typical of species like zebra and quagga mussels that can foul docks, piers, dams, pilings as well as boats, buoys, and recreational equipment. Invasive animals have significant impacts on human health. The introduction of disease vectors like mosquitoes, such as the Asian tiger mosquito, has changed the way visitors use parks. Africanized bees and imported fire ants have also restricted park usage in southern and southwestern national parks. Other introduced animals provide new vectors threatening human health, such as introduced

snails that are vectors for other human diseases. Human health and well-being can also be directly affected by introduced swine via vehicle collisions.

Some invasive animal species are regarded as beneficial through activities like sport fishing for introduced trout species. Such species of invasive animals, most introduced many years ago, have become valued either culturally or economically. When deciding what management actions to undertake, economic criteria must therefore be integrated with cultural criteria to determine "value" both in the present and the future.

In addition to being a management problem, invasive animals are becoming a public relations issue. In 2017, a number of independent newspaper stories in a number of different states reported state, tribes, or other federal agencies taking action on invasive animal challenges (appendix C). These challenges ranged from aquatic invaders to snakes and pigs and are either focused within national parks or on species likely to impact national park management. This coverage is paralleled by newspaper articles covering NPS management actions on invasive animals.

☐ Specific Finding 1c. The NPS currently lacks a comprehensive understanding of the impacts of invasive animals and the cost of appropriate effective invasive species management.

Despite a general understanding of the important threat to natural and cultural resources represented by invasive animals and comprehensive efforts by some parks to control them, the NPS has not created a servicewide plan to address their management. The NPS Inventory and Monitoring Program provides a potential geographically- and ecosystem-based overarching structure, but such work does not appear to be part of their mandate. When a servicewide approach to invasive plants was created in 2000, there was a general sense that attention to invasive animals would come later, but it has not. Formation of this Panel is part of the effort to remedy this situation.

☐ Specific Finding 1d. Management efforts by the NPS to date have been largely piecemeal, poorly coordinated, and severely under-funded.

The consequence is that park superintendents are left balancing difficult choices with no overarching guidance and losing battles where success might be attainable. The NPS is losing these battles at multiple levels, with some regions reporting being unable to convince some park staff, broadly, that invasive species represent a significant threat to park integrity and should be considered a priority for action. This stands in contrast to other federal governments, state legislatures, and tribes which have increased efforts to manage invasive animals.

The NPS has been aware for decades of the problems that invasive animals pose to achieving its mission. Further, NPS reports numerous efforts underway to control invasive species. Some of these efforts are isolated, uncoordinated, and largely underfunded. The consequence is a general record of failure to control invasive species across the system. Despite the national and global awareness of invasive animals, NPS managers are struggling to address the challenge of invasive species management. Based on interviews with managers, the constraints they list can be classified as leadership and servicewide coordination, capacity, park culture, social license - or broad social approval, and cross-boundary coordination.[xvi] We address each below with respect to NPS efforts to manage invasive species.

The existing investment on improving ecosystems through invasive animal species management is demonstrated through summary information on 80 NPS projects formulated for funding from 2000-2023.[xvii] Though the specific figures are difficult to interpret because they represent projects that parks would like to implement, it is clear that the majority of requests target just three feral species (hogs, cats, horses/burros). Most of the requests focus on fencing and target animal removal. Cats, fire ants, woolly adelgids, and feral hogs are the most frequent target of existing invasive animal species control efforts, each with more than 25 park units using resources on these invaders. [xviii] Expenditures match planning fairly well, with hogs, woolly adelgid, cat, and emerald ash borer leading the list for which parks have a management plan adopted or in development.[xix] Of course, animals are not the sole focus of invasive species management; a Department of the Interior (DOI) analysis estimates total NPS expenditures on invasive species to have been $38.7 million in fiscal year 2009.[xx]

The annual investment in invasive animal control, however, represents just a small fraction of the economic cost that these species impose on the resources and values protected by the NPS. Invasive animals can inflict significant damage on cultural resources, ecosystem services, outdoor recreation opportunities, and infrastructure. Given the nearly $12 billion maintenance backlog across the National

Park System, the impacts of invasive animal species on infrastructure are of particular importance. Some of the first observable impacts of invasive species may be on infrastructure, but little is known about those costs.[xxi] Existing studies have found that invasive zebra and quagga mussels are estimated to cost the power industry $440 million/year in the Great Lakes, with a nearly $1 billion/year impact on businesses and communities.[xxii] The U.S. Army Corps of Engineers estimates that these aquatic invaders could cause losses of $22 million/year in the Lake Tahoe basin alone. [xxiii] Understanding the extent to which invasive animals affect infrastructure costs in parks is difficult, yet increasingly important. Costs incurred by invasive animals include the cost of control, the cost of building new infrastructure to address invasive animals (e.g., fencing), the cost of impacts of invasive animals on existing infrastructure (e.g., water intake and zebra mussels), as well as the cost of reduced visitor access and enjoyment (loss of wildlife viewing opportunities), and increases in visitor risk (e.g., Africanized bees). DOI's Invasive Species Task Force is beginning work in 2017 to quantify the economic cost of invasive species on water and power production on DOI lands.[xxiv]

Despite a lack of prioritization or coordination by NPS, it is important to recognize that there are some bright spots of success. For example, Channel Islands National Park has successfully eradicated pigs, burros, deer, rats, elk, sheep, European rabbits, and golden eagles (a North American native, but self-colonized on the Islands, and non-destructively relocated due to impacts on bald eagles) from several islands under their management. Other bright spots for park management are in Table 3.

Key Finding 2. Managing invasive animals will require action starting at the highest levels, engaging all levels of NPS management, and will require changes in NPS culture and capacity.

☐ Specific Finding 2a. Coordinating efforts across the NPS for effective invasive animal management is a challenge that NPS can meet, but it will require changes in NPS organization, culture and capacity.

Consultation with park managers reported in the NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report suggests that there are five constraints to achieving servicewide effective action on invasive animals: (1) lack of leadership and servicewide coordination; (2) lack of capacity; (3) the need to change the culture; (4) the need to develop social license to manage; and (5) a lack of resources. The fourth issue, social license, is addressed in Specific Finding 4b, and the fifth in Specific Finding 5c.

Lack of leadership and servicewide coordination: Invasive animal species have not been declared a priority by the NPS leadership. The lack of a nationwide or, in most cases, regionwide initiative

Table 3. Examples of effective control and eradication of invasive animals in NPS units.

Invasive Animal	Park	Management Efforts	Effectiveness
Non-native fish	Organ Pipe Cactus National Monument	Invasive fish threatening the Quitobaquito pupfish were removed by draining the pond and reintroducing the endangered species	Entirely effective
Feral cats and mongoose	Hawai'i Volcanoes National Park	Removal of feral cats and introduced mongoose that were preying on native Nene goose combined with captive breeding and reintroduction of geese	Population decrease has been reversed though threat is ongoing
Lake trout	Yellowstone National Park	Introduced trout, eating and displacing Yellowstone cutthroat trout, controlled by gill net and sport fishing	Management underway, ongoing efforts are required
African oryx	White Sands National Monument	Released for hunting on adjacent federal property, the herd grew to 4000, causing extensive ecological damage	The herd has been eradicated
Feral and free ranging domestic cats	Hawai'i Volcanoes National Park	A five-mile-long fence erected to protect federally endangered Hawaiian petrel	To date effective
Burros	Grand Canyon National Park	A variety of methods and partnerships were developed to remove burros alive or lethally	Successful eradication was achieved

limits coordination from the region to the park level and the park-to-park level as well as support of individual parks' effort. At the park level, managers also face push-back or lack of support from park leadership. Superintendents may not prioritize invasive species management compared with other challenges or they may want to avoid the bureaucratic obstacles to meeting compliance requirements for management efforts. Managers struggle to communicate the importance of such efforts to their leadership to garner support for invasive species management.

Lack of capacity: Parks must balance many competing demands for their limited staff and funding resources. This is no different for invasive animal species and likely even more acute given unique aspects of this issue (e.g., delays between when an invasive species establishes and its effects are felt, invasive populations and impacts tend to grow in the absence of interventions, invasive species management is not explicitly funded, management requires long-term funding, can be costly, and there is high uncertainty in effectiveness).

Staff capacity is particularly problematic for invasive animal species management. Many parks have no specific natural resource staff, or anyone knowledgeable and well-trained about invasive animal management. All staff tend to be time-limited and spread thin, limiting their ability to proactively address this issue, coordinate with other agencies and neighboring land managers, and plan and implement appropriate management. Similarly, they may not have the capacity to address compliance issues that may be associated with invasive animal species management.

Staff also face limited information for making decisions about what to do and how to do it. They may not have access to or know where to access even basic ecology and management information. They may also lack the incentives or the ability to seek information. Some staff believe this issue could be partially remedied with a central clearinghouse of the most relevant information for them, in an easily accessible manner. Notably, though, parks felt that decision support tools were much less useful than the need for staff and funding capacity and training. Lack of monitoring efforts focused on invasive species also limits parks, as the NPS Inventory and Monitoring effort's focus on long term monitoring is not viewed as being useful in management of such species.

Culture change: Cultural constraints to action exist within NPS. Parks and leadership tend to be reactive, rather than proactive. They are often overloaded and address the issues that are most urgent at the moment. Invasive species may not make it to the top of this list as their effects may be less apparent until they are so widespread that it will be extremely challenging and costly to address. Under a culture that often demands attention on the immediate, room needs to be made to incentivize action on the chronic, and important.

☐ Specific Finding 2b. The NPS can be organized to provide effective management of invasive animals.

Our national parks are managed to preserve unimpaired the natural and cultural resources of the nation. This mission is under a deep and immediate threat as a consequence of invasive species. Despite these challenges there are bright spots among parks where park management is confronting invasive species challenges and succeeding.

Engagement by NPS leadership in the challenge of managing invasive animals can expand and magnify these examples of a culture of success on invasive animal management while maintaining the integrity of park superintendents to manage their own parks. The NPS can formally recognize that invasive species represent a crisis on par with those three major crises that drove servicewide change: first, the overabundance of ungulates due to predator control that led to the Leopold Report in the 1960s; second, the Yellowstone fire crisis that led to a new age of wildfire awareness in this country; and third, the recognition of the importance of climate change that led to the report Leopold Revisited: Resource Stewardship in the National Parks.

Resource management agencies have embarked on programs to address climate change as a major threat to ecosystems. NPS has embraced as its priority addressing unmet infrastructure needs. Invasive species represent a threat that is as significant as the threat of climate change except that it does not loom in the future; its effects are already being felt.

The NPS could be a leader in helping the American public understand the nature and threat of invasive species to America's ecosystems. America has an enduring love for its national parks, and the NPS could use parks as educational platforms to show what measures are needed to prevent and control harmful invasive species. The public's respect and trust for the NPS places the service in a good position to engage them concerning the need for some difficult and controversial choices such as lethal control of vertebrates, constraining pet ownership, or constraining the freedom to move boats from one waterbody to another.

More than just educating the public, the NPS could also lead active stewardship efforts and lead on experimenting with technological innovation to address some of the most severe problems facing parks. Partnering with technology developers could magnify these successes by offering incentives for actively addressing invasive species challenges.

Tackling the invasive species problem requires action at the highest levels because of the structural constraints that currently limit attention to this pressing problem. Four examples illustrate such a need. Many invasive species eradication and control programs require difficult negotiations with the public and stakeholder groups. Line officers, incentivized to move across parks for career advancement, can create a culture of passing hard negotiations and decisions along to successors. Second, park visitor management challenges are frequently given higher priority than natural and cultural resources, and in the resource-limited situations common in the NPS, some park superintendents have paid little attention to invasive animal species. Third, controlling invasives often requires active and sustained management, as well as monitoring to determine if actions are effective. Parks are often inadequately staffed to allow appropriate and effective management and monitoring actions and inventory and monitoring networks have not adapted to provide control efficacy monitoring. Fourth, changing the culture of the U.S. with respect to invasive species requires a shift toward a balanced portrayal of both positive and negative aspects of nature in parks. Changing the NPS to deal with the threat of invasive species is possible if it is addressed at all levels of the organization.

Key Finding 3. Prevention, eradication, containment, and control of invasive animals cannot be addressed by individual parks themselves, but require proactive coordinated institutional action amongst multiple land managers at the land and seascape scale.

☐ Specific Finding 3a. Invasive species are not constrained by jurisdictional boundaries.

Invasive animal species arrive in park units in one of three possible ways: 1) intentional releases; 2) unintentional releases; and 3) range shifts -- often as the result of changes in resource availability, land use, climate, etc.[xxv] Each of these three can be driven by one of several motivations and have their own impacts on park resources.

Globalization, with resulting increases in trade, transport, travel, and tourism is the major factor driving the global increase in invasive species. Invasions do not usually begin in parks, but instead invasive species become resident in parks in the course of their invasive spread. When invasive animals are stocked in parks such as for fishing and occasionally hunting they are usually already invasive in other parts of the landscape. As a result, the NPS must work with land managers outside the boundary of parks to detect and manage species before they arrive in parks.

☐ Specific Finding 3b. Cross-boundary action is required to manage invasive animals.

Parks are typically bordered by a set of public and private lands under a diverse array of management. Effective communication and collaboration with neighboring jurisdictions is of critical importance in the prevention and management of invasive species. These neighboring landowners and managers may have different priorities, limiting the opportunity for partnering together to address invasive animal species. Yet, if they are not collaborating with the parks, addressing invasive animal species will be ineffective, as the species will likely continue to cross into the park.

☐ Specific Finding 3c. Proactive management is a vital part of invasive animal management.

Opportunities exist to reduce the likelihood of invasion or its impacts at several steps in the invasion process (Figure 1). Steps can be taken at borders

to prevent introductions associated with particular pathways including shipments of pets and ornamental species, transport via ship's hulls and ballast water transport.[xxvi] Programs involving early detection and rapid response (EDRR) can increase the likelihood that new invasions are quickly identified and eradicated before they can become established. Park visitors can also be educated about the damage done by releasing pets in parks. Species that have become too widely established to be eradicated can still undergo local reduction aimed at containing or at least slowing the spread of the invasion, which will reduce impacts over time. As depicted by the colored histogram bars (Figure 1) depicting costs, prevention has much lower direct costs than long-term control. This does not include the cost of loss of ecosystem value incurred when controlling an invasive species that is causing harm.

Despite the fact that prevention efforts typically cost less[xxvii] than either eradication or control[xxviii], the challenge in investing in prevention is that it is: (a) difficult sell to the public when it involves compromising park use; (b) difficult to sell to park administrators with many pressing financial needs; (c) difficult to demonstrate a return on the investment; and (d) usually best done with substantial partnering. Unfortunately, prevention is rarely completely effective and so needs to be accompanied by investments in eradication and control. The consequence is that there are few prevention programs other than on aquatic invasive invertebrates and plants that have been viewed as sufficiently important to warrant preventative measures.

Evidence suggests that NPS has, to date, been far more likely to engage in eradication (e.g., feral hogs), and long term control (numerous other feral hog examples) than in prevention management. Despite the lack of monitoring programs, some parks report opportunistic sightings (or sign) of invasive animal species that do not yet occur in parks, but occur adjacent to park boundaries. Top species being reported by park units are emerald ash borer, gypsy moth, feral hog, hemlock woolly adelgid, Asian longhorned beetle, golden chain tunicate, and quagga mussel.[xxix] While monitoring alone cannot prevent the arrival of these species, monitoring may allow early action that can reduce their impacts and costs of control.

Typically the impacts caused by an invasive species increase over time as population densities and the area affected by the invader increase. While impacts

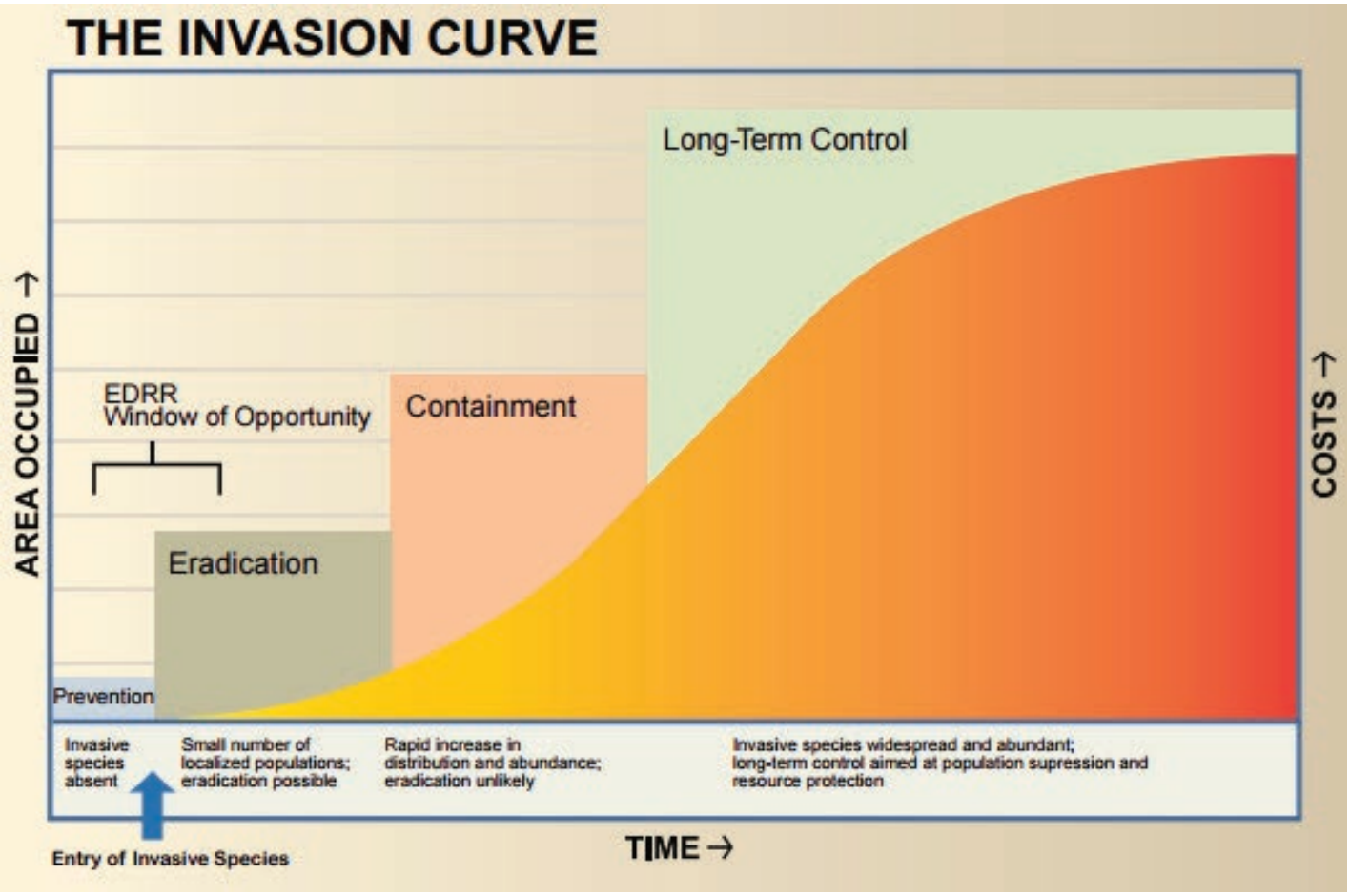


Figure 1. The Invasion Curve[xxx]

may not be eliminated by management, a reduction or delay of impacts also can provide value. For example, slowing the spread of hemlock woolly adelgid into NPS forests may increase the number of years that visitors can enjoy a high quality recreation experience, prior to hemlock loss. Similarly, treatment of high value ash trees (e.g., near picnic areas) to protect them from emerald ash borer invasion can maintain an area's aesthetic values and avoid costly tree removal.

In some cases, existing efforts to control invasive animals are just not effective. Everglades National Park (data provided by NPS Biological Resources Division) was established in 1947 to preserve the biological diversity and resources of the Everglades ecosystems. The 1.5 million acre park, a World Heritage Site, was the first park in American history to be permanently protected not for its scenic value, but for the benefit of the unique diversity of life. The park is now seriously threatened by invasive animals and invasive plants. Invasive animals, many escaped or released from the pet trade, now compete with, and prey on, native species. The invasive animals include reptiles, amphibians, birds, mammals, freshwater and salt-water fish species. Of particular importance for the harm they are doing to native species are lizards and snakes. A population of Burmese pythons expanding from Everglades National Park is conservatively estimated to number in the tens to hundreds of thousands. Boa constrictors are known to be established in south Florida, and recent evidence suggests that a reproducing population of northern African pythons exists there as well. Other feral species of large constrictor snakes also have been sighted or caught. These large snakes, particularly Burmese pythons are already responsible for drops of 90% in medium and large native mammals and prey on native birds as well. They have the potential to appreciably alter the natural communities in south Everglades National Park and beyond. Attempts to control the snakes have been virtually ineffective and pythons are likely to cause the extinction of at-risk species, since they can thrive on alternate prey as they drive the vulnerable prey to extinction with biodiversity, financial, and visitor experience impacts.

☐ Specific Finding 3d. To effectively manage the breadth and impact of invasive animals, the NPS will need to invest much more heavily in partnerships with other federal, state, and local agencies and organizations.

Some parks have developed robust inter-agency, transboundary partnerships that have been effective at leveraging resources and addressing resource management challenges. Parks can find great value and ultimately increased effectiveness at a lower cost, by engaging broadly in invasive species problems. Case studies of this partnering within the NPS are numerous (Hawaii Volcanoes National Park, Everglades National Park[xxxi], Yellowstone National Park[xxxii]), however in many cases this was learned by experience after parks initially launched into programs by themselves and then learned that it works better to partner and engage with stakeholders.

Partnering can be a challenge because different stakeholder groups and communities bring both different values and knowledge to the table. Structuring programs on invasive species that incorporate the concerns of stakeholder groups takes time, but is crucial. Parks would be well advised to build robust programs of stakeholder engagement as soon as possible.

Table 4. Two case studies where parks have been effective at creating tools to help increase public support for potentially contentious invasive species management action.

Park	Issue	Action	Lesson Learned	Source
Biscayne National Park	Lionfish	Lionfish collected by the NPS are taken to classrooms for dissection by students.	Concentrated efforts are effective in educating the public about the challenge of lionfish in coastal waters	GAO, 2015, p. 68
Cumberland Island National Seashore	Mammals (horses and hogs), and other invasive species	Experimental trial of non-personal, flyer based education versus personal, audio-based (ranger talks) on increasing visitor knowledge, awareness and support for control programs.	Both treatments increased knowledge and awareness relative to controls. Their overall effect on attitudes and management preferences were minimal, but the interpersonal appeared to be more effective than the flyer at increasing awareness and generating support for management	Sharp et al. 2012

Anecdotal reports suggest a lack of resources or incentives for parks to engage in outside partnerships for the purpose of invasive species control. There are, of course, exceptions such as the multi-organization, international partnership for invasive animal management in Channel Islands National Park[xxxiii] that included public information about the potentially controversial animal control programs that were deployed.[xxxiv] Partnership at a servicewide level can also take place, as exemplified by NPS' proactive engagement in developing public support for invasive species prevention through the "Stop Aquatic Hitchhikers" campaign, which NPS has helped fund.[xxxv]

Organizations, such as the Collaboration for Environmental Evidence[xxxvi] and Conservation Evidence[xxxvii] specifically seek to identify what does and does not work in conservation based on empirical evidence. These organizations are potential partners in the quest to acquire and share state of the art knowledge on invasive species management. Finally, a suite of boundary organizations (organizations that facilitate collaboration and information flow between diverse other organizations or programs, e.g., US DOI Landscape Conservation Cooperatives, NGO's such as Point Blue Conservation Science) exist for the purpose of translating science into action and function as information aggregators as well as focusing on acquisition of needed knowledge for resource management.

In all cases, there is a need for the NPS to systematically think through how to partner with which organizations, for what purposes. Fully engaging in preserving native ecosystems from the threat of invasive species is a group effort. NPS coordination must engage strategically in these problems and leverage the information and knowledge partnerships that are available with scientific societies, colleges and universities, other agencies and businesses (e.g. marketing firms).

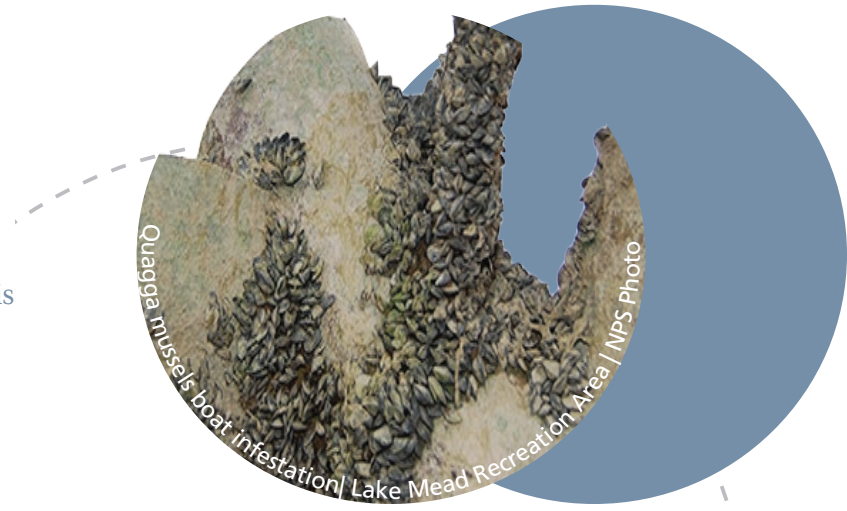
Key Finding 4. Effective management of invasive animals will require stakeholder engagement, education, and behavior change.

☐ Specific Finding 4a. Gaining public support for broader management goals and management actions is essential for successful management.

Engaging the public through various means including education and outreach early on can increase the likelihood of gaining support for management strategies in general, and prevention of invasive species introduction in particular. Evidence of the importance of public education and garnering public support abounds within NPS invasive species management examples, but could be strengthened through consistent messaging. For example, after an initial attempt to control lake trout in Yellowstone Lake was met with resistance from fishing advocacy groups, a shifting of the focus from invasive species removal[xxxviii] to ecosystem recovery[xxxix] resulted in growing public support for the program.[xl] In another example, increasing public awareness about how aquatic invasive species are introduced, and the impacts and threats posed by them, has been identified by NPS and other agencies as an important component.[xli] Evaluating the effectiveness of public awareness programs and learning from them can improve the application of lessons learned across the NPS (Table 4).

☐ Specific Finding 4b. Stakeholder engagement through participatory approaches is needed to gain 'social license' for effective invasive animal management and to minimize conflict.

The success of invasive species management activities often relies as much on public engagement and the earning of a social license to operate[xlii] as on science and technology. Conflict over whether and how a species should be managed can become highly contested and political, with negative media coverage. Further, human action can influence whether management will continue to be successful (e.g., whether people continue to introduce a species). There is often a lack of support for management when action targets charismatic species, such as feral horses, feral cats, or mountain goats. Similarly, when visitors' recreational experiences are limited



by public health or safety issues, either due to the species or the management activities, they tend to be more vocal for and/or against management. Public opinion also influences what control methods can be considered particularly when applied to species that have a public constituency such as free-range and feral cats.

Conflict can also be driven by conflicting values towards wildlife and opinions on ethical treatment of animals. Conflict can occur due to differing priorities and relationship to species. For example, an invasive species could be a favorite game species to some and a disease vector to others. Attempts by NPS to incorporate hunter desires by allowing hunting of invasive animals such as goats or hogs has not been successful either in assuaging hunters or controlling the impacts of the invasive species. Such situations can be further exacerbated if stakeholders feel that managers are not appropriately considering their voices or failing to be transparent in decision-making.

A variety of studies, reports, and experiences[xliii] point to the conclusion that while the public holds parks in high esteem, it does not distinguish well between native and non-native species, does not understand that non-native species represent novel stressors to ecosystems that can be particularly damaging, and does not like lethal control of vertebrates. These factors pose challenges to invasive animal control since nearly every program of prevention, eradication, and containment can only be effective with stakeholder engagement and public support.

Identifying who should be considered a stakeholder and actively engaging them is a crucial piece of working on social license. The best approach for parks to deal with these human dimensions issues is by developing a strategic communications and engagement strategy to proactively: 1) identify the current and potential stakeholders (a person who may affect or may be affected by management decisions); 2) employ social science methods (e.g., focus groups, surveys, social feasibility assessments) or stakeholder engagement methods (e.g., public meetings, solicitation of comments)[xliv] to better understand stakeholders and whether an invasive species management project is justifiable or risky; and 3) involve stakeholders (e.g., task forces, large group decision-making processes, negotiated agreements) throughout the entire process to build relationships and trust and find more effective solutions. Employing participatory approaches is perceived to be democratic, and thus, more appropriate for federal agencies managing in the interests of people. Further, projects that result from such engagement approaches are more likely to garner and maintain social support.

☐ Specific Finding 4c. Changing human behavior is a key part of achieving active support for invasive animal management.

While improving communications with stakeholders can be a positive first step, in most cases typical communications or interpretation alone are not adequate, but changes in behavior are required. Often efforts directed only at communication are based on a faulty one-way model, called the "information deficit" model[xlv], whereby a conservation professional provides facts and figures (or knowledge) with the hopes that this information will change people's opinions, cause them to be more favorable, or cause them to take some action. Extensive research has shown that knowledge gain does not translate into action. Action is also driven by many other factors including values, attitudes, skills, and norms.
In some cases, where a behavior change is necessary (e.g., cleaning boats after using lakes to limit the spread of invasive species), rather than a change in social acceptance, social marketing approaches may be appropriate. Some have argued that these approaches are less desirable than deliberative, participatory approaches because they are top-down and paternalistic.[xlvi] Yet, social marketing can work well when appropriate behaviors are selected. Appropriate behaviors are those that would actually impact the invasive species issue at hand, that have high probability of being adopted, and that currently a low proportion of individuals engage in.[xlvii] To determine these characteristics of the behavior accurately, social science research will be necessary. Parks can also join in efforts that are targeting human behavior to limit invasive species introductions beyond their park boundaries. For example, Everglades National Park has been part of the "Don't let it loose! Be a responsible pet owner" campaigns.[xlviii] Other campaigns and educational resources are available from the Invasive Species Action Network.[xlix]

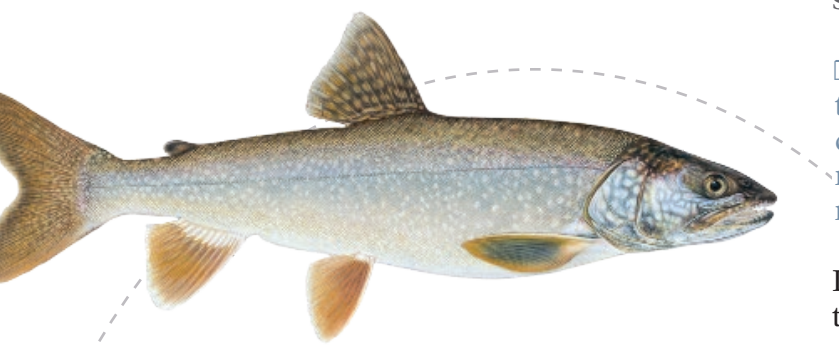
☐ Specific Finding 4d. Engaging the public through community science can contribute to effective management.

Parks can use volunteer assistance from the public for purposes of detection, surveillance, and management of invasive species. Deploying community scientists can help a park address invasive issues through volunteers as well as increasing public buy-in of

invasive species management through hands-on learning. To be done well managing volunteers and community science programs requires staff capacity as well as training programs and adequate data management to address error from non-expert data collection. For this reason, partnering with national programs for community science, such as eBird[1] (an extensive internal community science program for studying birds) or iNaturalist[1i] (a community science program frequently used for BioBlitz events), should be considered for the species and locations where such programs already exist. While opportunities also exist for community member participation in management and eradication programs, these programs do not currently exist in most locations. An example of a park that tried such an approach is Everglades National Park for their Burmese Python issue. Citizens were recruited to record observations of pythons through the EDDMapS website or smart-phone application and assist in their removal. The park struggled to incentivize voluntary participation in this program, particularly because pythons are difficult to detect[1ii], and, even with the citizen participation, the park has struggled with the python issue largely due to lack of appropriate technology and the life history characteristics of the animal.

☐ Specific Finding 4e. The NPS is well-poised, as a consequence of their substantial investment in education and interpretation, to develop effective public engagement on the issue of invasive species, but doing so will require national leadership.

Though changing behavior is difficult and takes more than education, parks can partially address this challenge through their existing interpretive programs. There is an opportunity to leverage the public contact that exists within the interpretive functions of parks to strategically increase public awareness of invasive species problems. Like most endeavors, national level attention to providing incentives for these interactions is necessary to create the cultural change required to address invasive animals in a broad and integrated fashion. Parks, traditionally, have focused on educating visitors about positive features of individual parks or they may be limited to talking about priorities laid out by the leadership. Building the capacity for interpretive programs to engage in a partnering role with resource management to create the social license to successfully deploy invasive species programs will be an institutional challenge.



Lake Trout, NPS Photo.

Parks could better harness the power of their interpretive staff to effectively communicate with visitors about invasive species management. They should also consider trying to work with state, federal and county agencies to engage with less-often targeted groups who affect species introductions like anglers, hunters, boaters and concessionaires. One issue to be addressed is invasive species denialism, which is increasing in the popular press, along with science denialism[1iii]. Combating denialism can be challenging and often backfires when more scientific information is presented because individuals may process it in a biased manner (i.e., they view it through their existing lens, and it reinforces what they already thought was right or wrong). Parks can most effectively communicate by considering that information will be processed through the lens of people's worldviews and group identities. By effectively debunking the information that supports invasive species denialism, interpreters can then replace it with more accurate information about invasive species.[1iv] Additionally, parks should emphasize the positive outcomes of invasive species management (e.g., healthy ecosystems or the recovery of a declining native species), rather than the doom and gloom of the impacts of the invasive species or expressing the goal as invasive species removal.

Key Finding 5. The NPS has the opportunity to address invasive animal management through emerging best practices in structured decision support for natural resource management.

☐ Specific Finding 5a. Developing the capacity for the NPS to organize resource management using decision frameworks will increase the potential for realizing a future state of effective invasive animal management.

Invasive species management decisions fall within the complex challenge of deploying limited resources among challenges that overwhelm those resources. Recently developed decision support frameworks

can help reduce social pushback as NPS makes difficult decisions such as deploying lethal control of vertebrates.

Natural resource management is in the midst of significant change involving adopting formal decision support tactics in order to better engage partners and stakeholders, increase decision transparency and increase efficient use of limited resources. This emerging field borrows from the disciplines of resource economics, decision science, geospatial analysis and project planning to create a set of frameworks and tools for decision support. It emphasizes establishing clear objectives that focus on positive outcomes. For example, structured decision-making highlights that the objective of controlling an invasive species is a "means" for achieving a "fundamental objective", such as creating healthy, functioning, self-sustaining native species dominated ecosystems.

Survey responses of resource managers[lv] along with the Panel's discussion with NPS staff[lvi] indicate that NPS has not yet systematically embraced structured decision support in resource management. In fact, there appears to be an impression that priority ranking checklists, and other such tools, represent sufficient decision support; indicating a fundamental misunderstanding of what decision support can offer. Given that restoring native ecosystem functions that have been degraded by invasive animals is often expensive and socially unpopular, adopting innovative decision support frameworks, especially if stakeholders are engaged in their design, is likely to considerably increase effectiveness. NPS has the capacity and opportunity to systematically adopt socially engaged decision support that may allow NPS to tackle difficult management issues with public support.

We offer five examples of how an approach that uses structured decision-making might benefit different aspects of the challenges facing NPS managers dealing with invasive species. The five examples span a range of challenges that NPS staff identified as those facing managers when confronting invasive species management issues. As such, the examples illustrate the breadth of support, beyond merely prioritizing actions, that can be gained by formally integrating decision support structures in natural resource management decisions.

Example 1. Engaging stakeholders in identifying and achieving fundamental objectives can reduce conflict. Yellowstone National Park had a problem with non-native fish. Non-native lake trout, introduced in 1994, were outcompeting native cutthroat trout, resulting in a collapse of this important river fish.

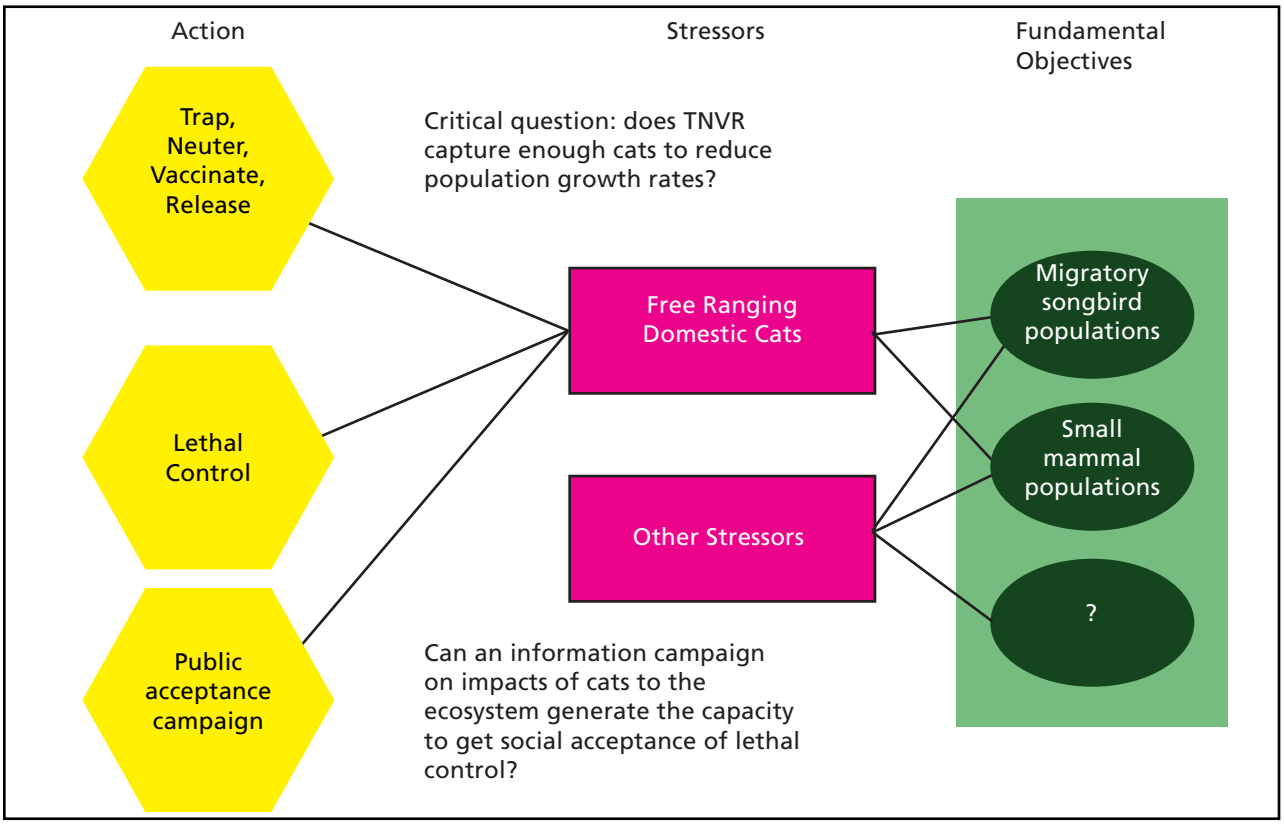


Figure 2. An analysis of potential cause and effect relationships is needed in order to devise an appropriate management strategy.

Deciding to act, the park began a program to remove lake trout. Billed as a lake trout removal program, there were soon irate fishermen contacting legislators and administrators in Washington, D.C. to put an end to the killing of the valued, but non-native, sportfish and so the program was shut down. It took a major reframing of the problem, explaining to fisherman the impact lake trout were having on cutthroat trout, and ultimately brown bears, to move forward. Several years later the program to reduce or eliminate lake trout is thriving and progress is being made with clear support of stakeholders engaged in the fundamental objective of improving ecosystem health.

A more deliberative process including structured decision-making would have been to identify the fundamental objective (a healthy, native-fish dominated lake system), engaging stakeholders of all kinds (lake trout fishers, river fishers and bear enthusiasts) in the challenge. Focusing on the positive fundamental objective (protect bears and the aquatic ecosystem upon which they depend) moves the focus from the proximate objective (eliminating lake trout) and action (killing fish) that, as such, may be objectionable to particular constituencies, and allow the dialogue that will, ultimately, be required in order to succeed.

Example 2. Developing a clear cause-and-effect hypothesis can facilitate evaluation of the likelihood that proposed action will lead to success. Free-ranging cats on some NPS sites have been implicated in declining bird and small mammal populations, as well as exposing humans to feline toxoplasmosis. Some NPS entities have engaged with the Humane Society on Trap, Vaccinate, Neuter, and Release (TVNR) programs to reduce cat impacts, but it is unclear if these efforts are reducing cat populations or their environmental impacts. An analysis of potential cause and effect relationships is needed in order to devise an appropriate management strategy. An effective decision support tool for complex ecosystem management problems is to develop a conceptual model of potential actions (Figure 2, yellow hexagons) and how they are envisioned to alleviate stressors (Figure 2, pink squares) in order to achieve objectives (Figure 2, green boxes). Using this approach, planners can evaluate evidence supporting the likelihood of one set of actions against another to achieve desired outcomes.

A common challenge has been that lethal control is not popular with stakeholders. Alternatively, trap, vaccinate, neuter, and release programs are popular, but may be ineffective at achieving the objective of reducing bird depredation. In either case, clearly laying out contrasting options and estimating how likely it is that an action will lead to outcomes allows the conversation with resource managers and stakeholders to focus on what is important: the natural ecosystem. If lethal control is untenable and capture and release ineffective, it forces consideration of alternative strategies.

Example 3. Engaging in formal cost benefit analysis can help focus management on the best objective for treatments. Economic analysis of benefits and costs can help identify the best strategy for a particular invader – whether to eradicate or contain the invasion, prevent its spread into the park from neighboring lands, or apply exclusion or suppression efforts to protect high-value, at-risk resources. The anticipated costs and benefits, over the long term, of various control options can be compared against likely outcomes achieved. This can help determine which strategy provides the biggest return on investment and whether management is even worthwhile. For example, economic modeling is being used to inform how highly valued endangered humpback chub populations can be maintained cost-effectively through mechanically controlling invasive rainbow trout, which prey on and compete with humpback chub. The analysis determines how many mechanical removals of rainbow trout should be implemented each year to cost-effectively maintain humpback chub populations over the long term. Analyses found that when rainbow trout populations are very high or very low, then no trout control is worthwhile, but at intermediate trout levels, four to six removals should be done each year. This type of modeling identifies a cost-effective strategy for helping to achieve endangered species conservation in Grand Canyon National Park.[1vii]

Example 4. Formal budget allocation tools can help improve efficiency of resource allocation and measurement of success. When faced with limited management resources, how should personnel, time and funds be allocated across potential projects or management challenges to get the biggest return on investment? Resource allocation choices may span projects within a park or across park units, and can be prioritized using a return on investment – or cost-effectiveness – framework to achieve the greatest benefits. For example, researchers found that using cost effectiveness measures to prioritize threat management actions such as fire, grazing, and feral cat management across sites could prevent the functional loss of mammals, birds, and reptiles over the next 20

years in north-western Australia.[1viii] Similarly, return on investment analyses have been used to prioritize islands for rat eradication[1ix] and to prioritize small mammal eradication across islands to provide the greatest ecological gains in terms of rare birds protected or rare species conserved. Accounting for differences in benefits, costs, and effectiveness across islands led to substantially higher conservation outcomes.

Finally, New Zealand has adopted a prioritization scheme for endangered species that explicitly includes measures of cost, likelihood of success and perceived benefit.[1x] Using this system of formally treating costs and benefits allowed New Zealand to reallocate resources to fund species that were most likely to respond positively to management actions. NPS faces similar challenges with funding invasive animal control measures. Allocating limited funding is complex. Deciding which problems should be funded through a centralized funding stream, or how much to allocate to invasive animals versus numerous other demands in order to achieve ecosystem management objectives requires both formal assessment of costs and benefits as well as careful monitoring of achievements.

Example 5. Measuring progress toward objectives facilitates adaptive management. It is not uncommon to confuse a "means", or method for achieving an objective, with the "end", or objective itself. It is easier to measure and report on "means" or "process indicators" such as "acres sprayed with pesticide" or "number of volunteer-days spent" and too often managers accept these in lieu of the more difficult-to-measure indicators of effectiveness. These might include "number of acres no-longer infested by invasive beetles" or even closer to the fundamental objective, "number of acres of previously beetle-infested forest now returned to healthy, native, vegetation." If this is the ultimate objective then it is important to recognize that invasive species control may be just one means for achieving this objective.

Recognizing that the condition of the ecosystem is the objective may require re-considering how ecosystem management is organized within NPS, whereby invasive plant teams may need to be partnered with invasive animal, restoration, and disturbance management teams to develop both proximate and ultimate measures of progress toward objectives. The Inventory and Monitoring Program might want to recognize the need to monitor the effectiveness of invasive animal management programs as a priority focus and realign resources to meet this need. There are numerous reasonable approaches to structuring decision support to foster engaged, transparent objective-oriented decisions. There are training programs available through the National Conservation Training Center (NCTC). Increasingly, organizations with which NPS must partner to succeed in improving ecosystems through invasive animal control will be framing their work within the context of risk assessment, structured decision-making, or project planning. For example, the U.S. Agency for International Development has begun to require that applicants for funds use the Open Standards for the Practice of Conservation[1xi] to apply for project funding. Given centralized resources within NPS, there is leverage to ask resource managers when applying for support to identify objectives, partners and stakeholders, and measures of progress. By doing so, NPS can create a culture of accountability to the public while retaining the authority of individual park superintendents.

❒ Specific Finding 5b. Effective invasive animal management will require changes in management.

The Panel could see a future in which NPS has recognized the threats posed by invasive species, and has therefore incorporated invasive species management into long range planning goals for the natural and cultural landscapes, as well as the day to day operations, of most of the parks in the system. In this desired future state the NPS serves on the DOI Invasive Species Task Force, exchanging best-practices with other agencies, and managing invasive species through a suite of national and local programs, each based upon the following strategies: cooperation and collaboration[1xii], inventory and monitoring[1xiii], prevention [1xiv], early detection and rapid response[1xv], treatment and control[1xvi], and restoration.[1xvii]

This future state is possible to achieve if the NPS would consider ways to increase the operational efficiencies and on-the-ground effectiveness of existing and new invasive management programs which include:

- Establishing a coordination mechanism that enables ongoing and timely information sharing among all of the park units (e.g., for providing alerts of new invasive species interceptions, or lessons learned regarding particular treatment methodologies);
- Providing national coordination of invasive animal management by creating National Invasive Animal Management Teams (NIAMT) or integrating invasive animal and invasive

plant management into National Invasive Species Management Teams (NISMT);
- Mainstreaming the invasive species issue into all NPS branches (from interpretation to resource management to human and financial resources) in order to capitalize on existing institutional resources;
- Integrating invasive species issues across relevant technical programs in order to leverage human, financial, and information resources (e.g., establishing a cross-cutting invasive species initiative among the Biological Resources Division, Water Resources Division and Inventory and Monitoring Division). This would help address the current lack of centralized planning that currently bedevils park managers;
- Leveraging management resources by establishing and/or expanding partnerships (e.g., by creating regional strike teams) with other government agencies (federal, state, territorial, tribal, local) that border Parks and/or otherwise share similar management concerns; and
- Capitalizing on public-private partnerships for all aspects of invasive species management. The Cooperative Invasive Species Management Areas[1xviii] can serve as a model for consideration. The work of a CISMA in the Florida Everglades[1xix] has enabled the effective control of invasive sacred ibis. Community science and other volunteer initiatives may also prove valuable from education, early detection and rapid responsive, monitoring, and mitigation perspectives.

One persistent challenge will be to place management support and action at the appropriate scale for effective action. The Panel found a perceived need to form a specialized invasive animal management team within NPS in order to elevate the problem to its appropriate importance. This approach would create benefit by addressing the issues detailed above and thereby fostering systemwide funding prioritization, centralized capacity, and the adoption of emerging technical solutions. NPS has the opportunity to elevate invasive animal management to its appropriate level of importance while also developing approaches that foster structured decision support that integrates across all (e.g., ecological, hydrological, historical, and infrastructural) resource management challenges facing park management. Maintaining and improving the state of our natural ecosystems is dependent upon addressing interacting stressors (e.g., invasive species, fire) and management levers (e.g., invasive species eradication/suppression, prescribed fire). The result is a need to create a focused capacity to strategically address the pressing issue of invasive animal species in such a way that fosters integrated resource management within parks that focus on fundamental values of ecosystem states, and not eradication targets.

☐ Specific Finding 5c. Effective invasive animal management will require increases in or redirection of funding.

The findings detailed above and those included in the new technology section below would all require new funding. Financial resource constraints at the national and park level necessitate that the NPS strategically institute a wide-range of funding and financial-leveraging initiatives that will enable the NPS to apply the most effective methodologies for invasive species prevention, eradication, and control in a timely manner. These initiatives will need to have the flexibility to enable the NPS to rapidly identify and respond to emerging priorities at all levels of park administration. In addition to adopting the operational efficiencies listed above, the NPS could:

- Integrate invasive species management into facilities (infrastructure) operations and maintenance budgets (e.g., for the management of "weeds" and "pests," including invasive rodents, stinging/biting insects, and wood borers);
- Establish a funding "challenge" to explicitly fund invasive species programs;
- Request the "Friends of the Park" organizations and the National Park Foundation raise funding to address specific invasive species needs at particular parks or parks within a particular region (e.g., lake trout in Yellowstone Lake[1xx])
- Work with the National Park Foundation to establish a "grand challenges" and/or "rapid response fund" for addressing high priority invasive species to the benefit of multiple parks.
- Work in partnerships to direct and secure mitigation or offset funding (e.g., oil spill, electricity infrastructure) to invasive species management activities on national parks.
- Apply structured decision-making approaches to prioritize invasive species management investments, as prioritization can both enhance effective use of existing resources and help to articulate what could be accomplished if additional resources were made available.
- Apply cost-benefit approaches alongside quantitative performance measures to create stopping rules to cease funding of projects that aren't meeting performance goals.

Managers emphasized in the NPS Biological

Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report that all such funding would need a flexible timeline (unlike existing servicewide funding for more general purposes), allowing parks to be responsive to time-sensitive management issues. Additionally, long term or consistent funding is needed as many invasive species issues will not be remedied within the timeline of one grant, and follow-up monitoring is necessary to ensure eradication is effective.

Key Finding 6. The NPS can become a major actor in developing, testing, and deploying new technologies and approaches.

☐ Specific Finding 6a. Successful management of invasive animals will require programs for information management and effectiveness monitoring.

Invasive species pose a unique threat to natural lands management and cultural sites because in the absence of interventions, their impacts typically increase, their arrival and impacts are difficult to predict, and effective management has proven difficult. These characteristics mean that effective management will be possible only with creation of, and support for, systems that capture and share knowledge generated by forecasting and management activities. While national parks each represent unique contexts (mission, resources, threats), developing system-wide capacities to support knowledge creation and sharing can help the overall NPS goal of managing invasive animals. The three options usually seen as available for managing invasive species are prevention, eradication and control (e.g. containment, suppression). Management of information relevant for each of these three options, including monitoring systems, would be greatly improved by building and using knowledge management systems and including more effective use of existing databases (e.g. Global Invasive Species Database[1xxi] appendix D) with information about potential impacts and management options.

Prevention: One of the most difficult, but often the most cost effective, means of managing invasive species is prevention. System-wide capacity to engage in strategic horizon scanning for potential new invaders and then dissemination of that information to potentially impacted parks would help individual parks reduce the likelihood of new invasions.[1xxii] Methods including eDNA and metabarcoding can alert managers to the presence of new invaders where they might not yet be detectable with standard methods.[1xxiii] Improving methods for early detection will lead increasingly to earlier and thus more effective rapid responses to new invaders. Parks also would benefit by coordinating with various state, federal and international organizations in order to fully understand potential new threats – from both neighboring lands and from other regions. An increase in NPS capacity for forecasting threats and alerting parks could contribute significantly to effective prevention and early detection and rapid response programs.

Eradication: Tools and technologies for eradication are constantly changing (see section below). Learning about effective eradication methods can be challenging, since actors engaged in efforts face resource limits for both learning and sharing information. These tools include new genetic methods (CRISPR) which allow creation and insertion of genes that would disable invaders. Such tools can be used with gene drive manipulation that allows the rapid movement of these useful genes throughout the invading populations of rodents and mosquitos.[1xxiv] Managers engaged in eradication also often are not rewarded for participating in knowledge-sharing devices that range from peer reviewed publication to online practice-centered databases to communities of practice that meet virtually. System-wide rewards can be very helpful for incentivizing knowledge sharing and reducing barriers. Knowledge sharing opportunities span a broad range, including meetings, webinars, newsletters, and searchable databases. However, a national or regional clearinghouse through a coordinator's office can greatly increase the efficiency of knowledge and technology transfer when time budgets to search for new information are limited.

Control: Deciding that eradication is not an attainable objective leaves managers with painful choices on whether to continue to spend limited resources on a battle that cannot be won. Factors that need to be weighed are whether containment, slowing the spread, or suppression efforts are effective and if they create ecological value that is commensurate with the cost.

Table 5. Overview of innovative mechanisms for managing invasive animals.

Innovation	Mechanism	Examples	Reference
Self-resetting traps	Target species is attracted by a lure, sets off a trigger that in turn activates a gas-propelled bolt and kills the animal instantly and humanely	Rodents, mongoose, lionfish	https://www.goodnature.co.nz/ https://robotsise.com/lionfish-project/
Remote triggering	Cell phones used for activating solenoids that trigger traps, net cannons and other devices	Feral hogs	https://www.pixcontroller.com/Raptor/Raptor-RemoteTrigger.htm
Species-specific toxicants	Differential species susceptibilities to chemicals	Sodium nitrite for feral hogs. Used as a food preservative; at high doses it reduces the ability of red blood cells to release oxygen to tissues. Feral hogs are highly sensitive to this toxicant. USDA are registering a bait product, called Hog-Gone with sodium nitrite for use in the US. Para-aminopropiophenone (PAPP) for feral cats and dogs are highly sensitive to PAPP, which is also considered to be humane.	https://www.aphis.usda.gov/wildlife_damage/nwrc/publications/12pubs/fagerstone121.pdf Eason, et al. 2014
	Species-specific enzymes	Norbormide for rats	Campbell et al. 2015
	RNA inhibitors (RNAi)	Developments underway for a suite of invertebrates. Potential for vertebrates also.	Campbell et al. 2015 USEPA, 2013
Toxicant delivery	Adoption of methods used elsewhere and setting precedents in the US	First aerial broadcast for invasive rodent eradication in the US was conducted on Anacapa Island, CA Channel Islands NP resulting in the successful eradication of invasive black rats	Howald, et al. 2009
	Novel way to deliver an aqueous solution containing the toxicant	Hydrating beads for toxicant delivery to ants	Boser, et al. 2017 https://www.nps.gov/chis/learn/management/ants.htm
	Aerial application of novel bait types required to stay in tree canopy	Aerial application of dead mice laced with acetaminophen with streamers to catch in vegetation for brown tree snake control by USDA	https://www.doi.gov/invasivespecies/innovation-summit-project
	Spraying measured dose of toxicant only to the target species, which is later licked off	'Spitfire' for rats and mustelids sprays as they pass through a tunnel is underway in New Zealand	Campbell et al. 2015
	Hog-Gone bait development is the Hog-Hopper bait dispenser, with a lid that few other animals besides feral pigs can access. Refinements are being made to make these increasingly feral-pig accessible only.	Grooming trap for feral cats sprays toxic gel onto the fur of the animal. The feral feline will then instinctively groom the gel from its body, ingesting a lethal dose of poison.	http://www.abc.net.au/news/rural/2016-04-20/feral-cat-control-robot-trialled-qld/7338848
	Species-specific bait stations	Hog-hopper bait dispenser for Hog-Gone bait, with a lid that few other animals besides feral hogs can access. Refinements are being made to make these increasingly feral hog accessible only.	https://www.aphis.usda.gov/wildlife_damage/nwrc/publications/12pubs/fagerstone121.pdf

Table 5 (continued). Overview of innovative mechanisms for managing invasive animals.

Innovation	Mechanism	Examples	Reference
"Judas" animal	Radio-telemetry collars are fitted to select animals (Judas animals), which are released and allowed to seek out conspecifics. Judas animals are then radio-tracked, and any accompanying un-collared animals can be shot, traps deployed at those locations or other methods employed	Feral goats, feral hog, carp, pythons. Recent developments involve the use of sterilized Judas animals, with hormone implants inducing estrus in females, increasing efficacy.	Taylor & Katahira, 1988; Campbell, et al. 2005; Campbell, et al. 2007
Creation of habitat islands	Fencing can be used to create 'mainland islands' which can then have invasive animals eradicated from within them.	Hawaiian petrel	https://www.nps.gov/havo/learn/news/20161024_pr_cat_fence.htm
Detection probability models	Detection probability models are used to determine the probability of whether a target species is present in an area based on the effort expended, often with a suite of different detection methods. These models can be used to determine the certainty that eradication is complete.	Feral hog eradication confirmation on Santa Cruz Island.	Ramsey et al. 2009
Drones and unmanned automated vehicles	Drones and unmanned automated vehicles (UAVs) can be configured with a variety of devices for detecting (e.g. thermal camera) or controlling (e.g. bait application) invasive animals.	Numerous	e.g. Gonzalez, et al. 2016
Environmental DNA	Water can be collected from a stream or other source and the sample checked for the DNA of a target specie or species	Aquatic species	https://www.nature.nps.gov/ParkScience/index.cfm?ArticleID=692
Sterile-male technique	Large scale programs using traditional (irradiated) sterile males have been used to eradicate other invertebrate species. Gene editing techniques and other genetic approaches are also used to now produce sterile males for release.	Mosquitos, screw-worm	Dyck, et al. 2006; Ritchie & Johnson, 2017

New approaches to population modeling for damaging forest pests like Emerald Ash Borer can assist with developing strategies to minimize ecological impacts relative to the economic costs of control.[1xxv] These are difficult decisions that often require complex decision support (e.g., elicitation of stakeholder values, estimation of treatment impacts, cost – benefit assessment, futures discounting and assessing the value of delaying invasive species expansion). Complex knowledge of decision support is likely beyond the means of most parks, as evidenced by survey responses indicating that parks appear satisfied using score sheets in lieu of decision support. System-wide capacity to help parks make hard decisions regarding containment or suppression efforts requires a knowledge base that a coordinator's office could manage.

Monitoring: New developments in the field of monitoring focus on synthesizing evidence to address management questions at two levels: (1) did the action have its intended specific effect (ie, did an eradication program eradicate the target as well as expected) and (2) did the action result in achieving program objectives (ie, did the native species that were adversely impacted by the target species recover?). An apparent challenge within the NPS is that its existing Inventory and Monitoring Program was established by Congress in 1998 to facilitate understanding the presence and status of key resources within parks. It operates as 32 ecoregional teams servicing over 270 parks and focusing on previously established "Vital signs". The I&M Vital Signs monitoring structure favors investment in a set of long term metrics rather than targeted adaptive monitoring to measure the outcomes of management projects.
Recently emerging emphases on evidence-based ecosystem management have resulted in tools and processes for collecting, synthesizing and applying evidence from management actions into learning for adaptive management. For example, monitoring programs for invasive lionfish in the Caribbean (including in NPS locations in the US Virgin Islands) and the associated knowledge databases maintained by USGS[1xxvi] can greatly assist decisions regarding local containment vs eradication based on proximity of other populations and likelihood of re-invasions. In order to maximize the capacity for cross-park learning based on action outcomes as well as adaptive management within parks, NPS will need to evaluate whether or not the existing I&M programs have the capacity and structure to build on existing efforts. NPS will also need to ensure the integration of multiple programs working on restoration to create organization-wide, consistent support for active learning from management actions and if not, whether this should be a function of Inventory and Monitoring programs or if it belongs as a monitoring structure within park resource management teams.

☐ Specific Finding 6b. Innovation holds great promise for moving the NPS towards the efficient and effective management of invasive animals.

Although policy makers, land managers, and the public are increasingly aware of the invasive species issue, the commitment to problem resolution remains well below that needed to address the challenges posed by invasive animals. There are new technologies and approaches available for the NPS to consider that might significantly contribute to addressing invasive animal management and change the valence of such work from negative to positive.

Technology innovation can increase the efficacy of traditional methods for invasive species prevention, eradication, and control, as well as develop new approaches that enable more cost-efficient and effective outcomes. The NPS can foster technology innovation by engaging in partnerships with NGOs, universities, other government agencies, and for-profit entities to develop, test, implement or provide case studies and articulate challenges for improving invasive animal management in U.S. national parks, neighboring lands and waters.

A suite of innovations has recently become available around the world or are emerging technologies at varying stages of development that may be useful for managing invasive species impacting national parks (Table 5). Some of these technologies have already been deployed in national parks but there is great scope for more innovation and greater application.

Most existing approaches and tools have not proved effective in managing invasive animal species and as a result there is active experimentation with new tools. In late 2016, NISC hosted a meeting of US federal and non-federal experts to seek solutions to invasive species management challenges. Results from the meeting, emphasizing federal agency roles and opportunities, are available on the NISC website.[1xxvii] It is clear that: 1) existing tools and approaches are inadequate for the job; 2) new technologies with potential applicability in parks, such as genomic approaches, are being developed and should be critically examined by NPS; and 3) there is a very significant opportunity for the NPS to create an

atmosphere of leadership in developing and testing innovations to prevent, eradicate and control invasive animals. This work could be done by NPS staff, but would mostly consist of collaborations with outside experts. This approach would rely on a culture of support for innovation and testing and new sources of funding so as not to diminish already inadequate budgets. A "Grand Challenges" effort such as detailed above would be a possible mechanism for such a new program.

Conclusion

National parks used to be considered authentic representations of historical and valued ecosystems. Their management only entailed ensuring that they remained unimpaired. This is no longer the case. At this time the natural and cultural values of the national parks are under a deep and immediate threat from invasive animals. Some parks have responded in effective ways and developed coherent, science-based approaches to invasive animal control that should draw the attention of other parks. But the threat posed by invasive animals cannot be addressed on a park by park basis, it requires systemwide change.

The NPS has a window of opportunity now to meet this challenge and change the culture of the institution and of the public. Proactive management approaches to public lands management is a choice that needs to be embraced, starting at the highest levels of NPS and involving all parts of the organization. Coordinated and strategic deployment of management across boundaries can succeed at ensuring the ecological integrity of our parks into the future. Active resource stewardship is already recognized as a duty of park management.

The Panel has reached six major findings. First, that invasive animals pose a major threat to U.S. ecosystems and parks. Second, that this threat can be addressed by NPS through engagement at all levels of NPS management, and through changes in NPS culture and capacity. Third, that action by NPS cannot proceed park by park, but will require coordinated institutional action. Fourth, effective management of invasive animals will require stakeholder engagement, education, and behavior change. Fifth, structured decision support for natural resource management offers a rich set of tools to help NPS take action. And sixth, that there is an opportunity for NPS to become a major actor in developing, testing, and deploying new technologies and approaches.

These findings offer an opportunity for the NPS to work across boundaries, across disciplines, and apply decision-making tools to work with the American public to manage invasive animals and ensure the treasured values of our national parks. The recent report to NPS, Revisiting Leopold, establishes a vision for management toward continuous change with a focus on ecological integrity. It is time to apply this view to invasive animals and apply what we are already doing for climate change in parks to invasive animals.

The NPS could become the acknowledged leader in helping the American public embrace the reality that invasive species are threatening the integrity of America's ecosystems. America has an enduring love for its national parks and an enduring love of nature. NPS can help society understand that invasive species deeply threaten our capacity to steward natural and cultural resources for the enjoyment of this and future generations and that action can and must be taken.

Endnotes

[i] Science Panel on Invasive Animals Charge from NPS
[ii] NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report
[iii] Maxwell et al., 2016
[iv] Loss, S.R., T. Will and P.P. Marra. 2013. The impact of free-ranging domestic cats on wildlife of the United States. Nature v Communications | 4:1396 | DOI: 10.1038/ncomms2380
[v] Corey J.A. Bradshaw, Boris Leroy, Céline Bellard, David Roiz, Céline Albert, Alice Fournier, Morgane Barbet-Massin, Jean-Michel Salles, Frédéric Simard & Franck Courchamp. Massive yet grossly underestimated global costs of invasive insects. Nature Communications, October 2016 DOI: 10.1038/ncomms12986
[vi] Pimentel, 2007
[vii] Marbuah et al., 2014; McDermott et al., 2013
[viii] Paxton et al., 2016
[ix] https://drive.google.com/open?id=0Byqh3ehKf40_emE0WjRySUVhUWMhttps://drive.google.com/open?id=0Byqh3ehKf40_emE0WjRySUVhUWM
[x] Simberloff, D. 2017. Biological invasions in the national parks and in Park Science. pp. 161-188. InS.R. Beissinger, D.D. Ackerly, H. Doremus and G.E. Machlis (eds). Science, Conservation, and National Parks. University of California Press, Berkeley.
[xi] Hester, F. E. 1991. The U.S. National Park Service experience with exotic species. Natural Areas Journal 11: 127-128.
[xii] NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report
[xiii] Mack, R. N., D. Simberloff, W. M. Lonsdale, et al. 2000. Biological invasions: causes, epidemiology, global consequences, and control. Ecol. Appl. 10: 689-710.
[xiv] Mooney, H. A. and R. J. Hobbs. 2000. Invasive species in a changing world. Island Press, Washington, D.C.
[xv] https://www.nps.gov/havo/learn/nature/rapid-ohia-death.htm
[xvi] Based on our qualitative analysis of NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report interview results.
[xvii] NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report
[xviii] NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report
[xix] NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report
[xx] https://www.doi.gov/sites/doi.gov/files/uploads/DOI-Econ-Report-6-21-2011.pdf
[xxi] Invasive Species Advisory Committee. 2016. Invasive species impacts on infrastructure. U.S. Department of the Interior.
[xxii] Western Regional Panel on Aquatic Nuisance Species. 2010. Quagga-zebra mussel action plan for western U.S. waters. Submitted to the Aquatic Nuisance Species Task Force.
[xxiii] USACE (U.S. Army Corps of Engineers). 2009. Lake Tahoe Region Aquatic Invasive Species Management Plan, California - Nevada.
[xxiv] L. Richardson, personal communication
[xxv] Mack, R. N., D. Simberloff, W. M. Lonsdale, et al. 2000. Biological invasions: causes, epidemiology, global consequences, and control. Ecol. Appl. 10: 689-710.
[xxvi] Williams, S. L., I. C. Davidson, J. R. Pasari, et al. 2013. Managing multiple vectors for marine invasions in an increasingly connected world. Bioscience 63: 952-966.
[xxvii] Lodge, David M.; Williams, Susan; MacIsaac, Hugh J.; et al. Ecological Applications Volume: 16 Issue: 6 Pages: 2035-2054 Published: DEC 2006
[xxviii] Epanchin-Niell, R.S., 2017. Economics of invasive species policy and management. Biol. Invasions DOI 10.1007/s10530-017-1406-4
[xxix] NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report
[xxx] DOI, Safeguarding America's lands and waters from invasive species: A national framework for early detection and rapid response, 2016; Rodgers, L. South Florida Water Management District; Invasive Plants and Animals Policy Framework, State of Victoria, Department of Primary Industries, 2010
[xxxi] Krysko et al. 2016 New Florida Exotic Herps
[xxxii] Hallac, D.E., Bigelow, P., Koel, T., White, P.J. 2014. Noble versus native – The societal challenge of restoring native trout in Yellowstone National Park. Proceedings of the Wild Trout XI Symposium.
[xxxiii] https://www.nps.gov/chis/learn/nature/restoring-santa-cruz-island.htm
[xxxiv] https://www.nps.gov/chis/learn/nature/restoring-santa-cruz-island.htm
[xxxv] Wildlife Forever. 2013. National invasive species outreach and education. 2013 annual report: reaching millions and millions. Stop aquatic hitchhikers. (http://

www.wildlifeforever.org/ftpgetfile.php?id=664)
[xxxvi] http://www.environmentalevidence.org/
[xxxvii] http://www.conservationevidence.com/
[xxxviii] http://www.nytimes.com/2011/08/24/us/24trout.html
[xxxix] http://discovermagazine.com/2014/may/16-elk-vanishing-act
[xl] Hallac, D.E., Bigelow, P., Koel, T., White, P.J. 2014. Noble versus native – The societal challenge of restoring native trout in Yellowstone National Park. Proceedings of the Wild Trout XI Symposium.
[xli] GAO (United States Government Accountability Office). 2015. Aquatic invasive species: additional steps could help measure federal progress in achieving strategic goals.
[xlii] https://socialicense.com/definition.html
[xliii] http://www.rasmussenreports.com/public_content/lifestyle/general_lifestyle/august_2016/americans_praise_park_service_rate_number_of_parks_as_right
[xliv] See Decker, D.J., Riley, S.J., Siemer, W.F.(2012). Human Dimensions of Wildlife Management. 2nd edition, especially chapters 3, 10, and 11.
[xlv] Bucchi, M. (2008). Of deficits, deviations, and dialogues: Theories of public communication of science. In M. Bucchi & B. Trench (Eds.), Handbook of public communication of science and technology (pp. 57-76). London: Routledge.
[xlvi] Crowley et al 2017. Invasive species management will benefit from social impact assessment. Journal of Applied Ecology, 54, 351-357.
[xlvii] McKenzie-Mohr, D. (2011) Fostering sustainable behavior: Community-based social marketing. New Society Publishers. 192 pages.
[xlviii] http://www.dontletitloose.com/
[xlix] http://stopans.org/programs.html
[1] ebird.org
[1i] inaturalist.org
[1ii] Falk, B.G., Snow, R.W., & Reed, R.N. (2016). Prospects and limitations of citizen science in invasive species management: A case study with Burmese pythons in Everglades National Park. Everglades Invasive Species Southeastern Naturalist, 15 (8): 89-102.
[1iii] Ricciardi et al. Invasion science: A horizon scan of emerging challenging and opportunities. Trends in Ecology & Evolution.
[1iv] Lewandowky, S. et al (2012). Misinformation and its correction: Continued influence and successful debiasing. Psychological Science in the Public Interest, 13 (2), 106-131. https://doi.org/10.1177/1529100612451018
[1v] NPS Biological Resources Division, Invasive Animals in the National Park Service: Biodiversity Under Siege Report
[1vi] NPS - Glenn Plumb, Dave Hallac, Elaine F. Leslie, Terri Hogan
[1vii] This work is being conducted by Lucas S. Bair and Charles B. Yackulic at USGS, Michael R. Springborn at the University of California, Mathew N. Reimer at the University of Alaska, and Craig A. Bond at RAND Corporation.
[1viii] Carwardine et al 2012
[1ix] Capizzi et al 2010; Helmstedt et al. 2016
[1x] Joseph, L.N., Maloney, R.F., Possingham, H.P. 2009. Optimal Allocation of Resources among Threatened Species: a Project Prioritization Protocol. Conservation Biology 23:328-338.
[1xi] http://cmp-openstandards.org
[1xii] https://www.nature.nps.gov/biology/invasivespecies/Cooperation_and_Collaboration.cfm
[1xiii] https://www.nature.nps.gov/biology/invasivespecies/Inventory_and_Monitoring.cfm
[1xiv] https://www.nature.nps.gov/biology/invasivespecies/Prevention_single.cfm
[1xv] https://www.nature.nps.gov/biology/invasivespecies/Early_Detection_and_rapid_Response.cfm
[1xvi] https://www.nature.nps.gov/biology/invasivespecies/Treatment_and_Control.cfm
[1xvii] https://www.nature.nps.gov/biology/invasivespecies/Restoration.cfm
[1xviii] http://www.invasive.org/cisma
[1xix] https://evergladesrestoration.gov/content/ies/docs/Goal2_Case_Study_Sacred_Ibis.pdf
[1xx] https://www.yellowstone.org/trout
[1xxi] http://www.iucngisd.org/gisd/
[1xxii] Ricciardi et al. 2017
[1xxiii] Brown et al. 2016
[1xxiv] Piaggio, A., G. Segelbacher, P.J. Seddon, L. Alphey, E.L. Bennett, R.H. Carlson, R.M. Friedman, D. Kanavy, R. Phelan, K.H. Redford, M. Rosales, L. Slobodian, K. Wheeler. et al. 2016. Is it time for synthetic biodiversity conservation? Trends in Ecology and Evolution 32: 97-107.
[1xxv] McDermott and Finoff 2016
[1xxvi] https://nas.er.usgs.gov/
[1xxvii] http://www.invasivespeices.gov

Literature Cited

Blackburn, T.M., et al. 2014. A unified classification of alien species based on the magnitude of their environmental impacts. PLoS Biology 12: e1001850.

Boser, C., Hanna, C., Holway, D., Faulkner, K., Naughton, I., Merrill, K., Randall, J., Cory, C., Choe, D.H. and Morrison, S. (2017). 'Protocols for Argentine Ant Eradication in Conservation Areas'. Journal of Applied Entomology.

Burbidge, A.A., Johnson, K.A., Fuller, P.J., and Southgate, R.I. 1988. Aboriginal knowledge of the mammals of the central deserts of Australia. Australian Wildlife Research 15: 9-39.

Capizzi, D., Baccetti, N. and Sposimo, P., 2010. Prioritizing rat eradication on islands by cost and effectiveness to protect nesting seabirds. Biological conservation, 143(7): 1716-1727.

Campbell, K.J., Baxter, G.S., Murray, P.J., Coblentz, B.E. and Donlan, C.J. (2007). 'Development of a Prolonged Estrus Effect for Use in Judas Goats'. Applied Animal Behaviour Science 102:12-23.

Campbell, K.J., Baxter, G.S., Murray, P.J., Coblentz, B.E., Donlan, C.J. and Carrion G., V. (2005). 'Increasing the Efficacy of Judas Goats by Sterilisation and Pregnancy Termination'. Wildlife Research 32:737-743.

Campbell, K.J., Beek, J., Eason, C.T., Glen, A.S., Godwin, J., Gould, F., Holmes, N.D., Howald, G.R., Madden, F.M., Ponder, J.B., Threadgill, D.W., Wegmann, A. and Baxter, G.S. (2015). 'The Next Generation of Rodent Eradications: Innovative Technologies and Tools to Improve Species Specificity and Increase Their Feasibility on Islands'. Biological Conservation 185:47-58.

Carwardine, J., O'Connor, T., Legge, S., Mackey, B., Possingham, H. P. and Martin, T. G. (2012), Prioritizing threat management for biodiversity conservation. Conservation Letters, 5: 196–204. doi:10.1111/j.1755-263X.2012.00228.x

Colautti, R.I., Bailey, S.A., van Overdijk, C.D.A., Amundsen, K., and MacIsaac, H.J. 2006. Characterized and projected costs of nonindigenous species in Canada. Biological Invasions 8: 45–59.

Dyck, V.A., Hendrichs, J. and Robinson, A.S. (eds.) (2006). Sterile Insect Technique: Principles and Practice in Area-Wide Integrated Pest Management: Springer.

Eason, C.T., Miller, A., MacMorran, D.B. and Murphy, E.C. (2014). 'Toxicology and Ecotoxicology of Para-Aminopropiophenone (Papp)–a New Predator Control Tool for Stoats and Feral Cats in New Zealand'. New Zealand Journal of Ecology 38:177-188.

Gonzalez, L.F., Montes, G.A., Puig, E., Johnson, S., Mengersen, K. and Gaston, K.J. (2016). 'Unmanned Aerial Vehicles (Uavs) and Artificial Intelligence Revolutionizing Wildlife Monitoring and Conservation'. Sensors 16:97.

Gren, I-M., Isacs, L., and Carlsson, M. 2009. Costs of alien invasive species in Sweden. Ambio 38: 135–140.

Helmstedt, K. J., Shaw, J. D., Bode, M., Terauds, A., Springer, K., Robinson, S. A. and Possingham, H. P. (2016), Prioritizing eradication actions on islands: it's not all or nothing. J Appl Ecol, 53: 733–741. doi:10.1111/1365-2664.12599

Howald, G., Donlan, C., Faulkner, K., Ortega, S., Gellerman, H., Croll, D. and Tershy, B. (2009). 'Eradication of Black Rats Rattus Rattus from Anacapa Island'. Oryx 44:30-40.

Marbuah, G., Gren, I-M., and McKie, B. 2014. Economics of harmful invasive species: a review. Diversity 6: 500-523.

Maxwell, S.L., Fuller, R.A., Brooks, T.M., and Watson, J.E.M. 2016. The ravages of guns, nets and bulldozers. Nature 536: 143-145.

McDermott, S.M., Finnoff, D.C., and Shogren, J.F. 2013. The welfare impacts of an invasive species: endogenous vs. exogenous price models. Ecological Economics 85: 43-49.

NASEM (2016). Gene Drives on the Horizon: Advancing Science, Navigating Uncertainty, and Aligning Research with Public Values. Washington DC: Committee on Gene Drive Research in Non-Human Organisms: Recommendations for Responsible Conduct; Board on Life Sciences; Division on Earth and Life Studies; National Academies of Sciences, Engineering, and Medicine

National Park Service, Natural Resource Stewardship and Science Directorate - Biological Resources Management Division. Resnik, J.R. and G.E. Plumb. 2017. Biodiversity under Siege: State of the Knowledge on Invasive Animals in the National Park Service. Draft Natural Resource Report NPS/NRSS/BRD/NRR—2017/XXX.

Nentwig, Wolfgang; Bacher, Sven; Pysek, Petr; et al. 2016. The generic impact scoring system (GISS): a standardized tool to quantify the impacts of alien species. Environmental Monitoring and Assessment 188: 315 DOI 10.1007/s10661-016-5321-4.

Paxton, E.H., Camp, R.J., Gorresen, P.M., Crampton, L.H., Leonard, D.L. Jr., and VanderWerf, E.A. 2016. Collapsing avian community on a Hawaiian island. Science Advances 2: e1600029.

Pearce, F. 2015. The New Wild: Why Invasive Species will be Nature's Salvation. Beacon Press, Boston.

Pimentel, D. 2007. Environmental and economic costs of vertebrate species invasions into the United States. Managing Vertebrate Invasive Species. Paper 38.

Pimentel, D., McNair, S., Janecka, J., Wightman, J., Simmonds, C., O'Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T., and Tsomondo, T. 2001. Economic and environmental threats of alien plant, animal, and microbe invasions. Agriculture, Ecosystems and Environment 84: 1-20.

Pimentel, D., Zuniga, R., and Morrison, D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52: 273-288.

Ritchie, S.A. and Johnson, B.J. (2017). 'Advances in Vector Control Science: Rear-and-Release Strategies Show Promise… but Don't Forget the Basics'. The Journal of infectious diseases 215:S103-S108.

Rumerlova, Z., M. Vila, J. Pergl, W. Nentwig and P. Pysek. 2016. Scoring environmental and socioeconomic impacts of alien plants invasive in Europe. Biological Invasion 18: 3697-3711.

Schlaepfer, M.A., Sax, D.F., and Olden, J.D. 2010. The potential conservation value of non-native species. Conservation Biology 25: 428-437.

Simberloff D, Martin J-L, Genovesi P, et al. 2013. Impacts of biological invasions: what's what and the way forward. Trends Ecol Evol 28: 58–66.

Taylor, D. and Katahira, L. (1988). 'Radio Telemetry as an Aid in Eradicating Remnant Feral Goats'. Wildlife Society Bulletin 16:297-299.

USEPA (2013). White Paper on Rnai Technology as a Pesticide: Problem Formulation for Human Health and Ecological Risk Assessment. Washington: U.S. Environmental Protection Agency.

Vila, M., J. Espinar, M. Hejda, P. E. Hulme, V. Jarosik, J. L. Marono, J. Pergl, U. Schaffner, Y. Sun and P. Pysek. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecol. Lett. 14: 702-708.

Appendix A - Science Panel Members and Affiliations

Name	Affiliation	Email
Karl Campbell	Project Director - Island Conservation, Galápagos Islands, Ecuador	karl.campbell@islandconservation.org
Ashley Dayer	Assistant Professor of Human Dimensions - Department of Fish and Wildlife Conservation, Affiliated Faculty- Global Change Center, Virginia Tech, Blacksburg, VA	dayer@vt.edu
Chris Dickman	Professor - Faculty of Science, The University of Sydney, Sydney, Australia	chris.dickman@sydney.edu.au
Rebecca Epanchin-Niell	Fellow, Resources for the Future,Washington, D.C.	epanchin-niell@rff.org
Ted Grosholz	Professor and Specialist in Cooperative Extension- Dept of Environmental Science and Policy, University of California, Davis, CA	tedgrosholz@ucdavis.edu
Dave Hallac	Superintendent, Cape Hatteras National Seashore and the Outer Banks Group, Manteo, NC	david_hallac@nps.gov
Leslie Richardson	Economist, Environmental Quality Division, NPS	leslie_a_richardson@nps.gov
Mark Schwartz	Professor, Department of Environmental Science & Policy - University of California, Davis, CA	mwschwartz@ucdavis.edu
Kent H. Redford	Science Panel Chair, Archipelago Consulting, Portland, ME	redfordkh@gmail.com
NPS Consultants		
Elaine F. Leslie	Chief, Biological Resources Division, NPS	elaine_Leslie@nps.gov
Glenn Plumb	Chief Wildlife Biologist, NPS (retired)	glenn_plumb@nps.gov
Jessica Resnik	Wildlife Biologist, Invasive Animal Coordinator	jessica_resnik@nps.gov
Kassandra Hardy	Management Assistant, Landscape Initiatives, NPS	kassandra_hardy@nps.gov

Appendix B - Presentations from a Science Panel Meeting

Presentation Title	Presenter
Servicewide summary of situation with alien invasive animal species	Glenn Plumb, Chief, Wildlife Conservation Branch, NPS (retired)
Lessons from invasive alien plant control in NPS	Terri Hogan, Invasive Plant Coordinator, NPS
Aquatic alien invasive animal and NPS	Alan Ellsworth, Chief, Aquatic Systems Branch, NPS
Climate change, assisted migration	Mark Schwartz, Professor, U.C. Davis
Hawaii Volcanoes National Park and invasive animal species	Elaine Leslie, Chief, Biological Resources Division, NPS
Everglades National Park	Carol Mitchell, Chief, Resource Management and Science, Everglades National Park, NPS
Genomic technologies as new solutions to alien invasive animals	Ryan Phelan, Executive Director and Co-Founder, Revive and Restore
Commentary on the community and indigenous perspectives on alien invasive animals in Hawaii	Maka'ala Ka'aumoana, Watershed Community Group, Hawaii
The extent of the problem of invasive animal species across the US in general and federal lands in particular	Jamie Reaser, Executive Director, National Invasive Species Council
The issue of alien invasive animals species on NPS lands	Glenn Plumb, Chief, Wildlife Conservation Branch, NPS (retired)
A park management perspective on alien invasive animal species	Dave Hallac, Superintendent, Outer Banks Group, Cape Hatteras National Seashore, NPS
A community perspective on invasive alien species with attention to cats	Maka'ala Ka'aumoana, Watershed Community Group, Hawaii
Invasive species on islands and how to manage for them	Karl Campbell, Island Conservation
New genomic tools for addressing invasive animals	Ryan Phelan, Executive Director and Co-Founder, Revive and Restore
Cats as an environmental issue in the US	Pete Marra, Smithsonian
Cats as an environmental issue in Australia	Chris Dickman, Professor, University of Sydney
The role of cats in the US	Katie Lisnik, Humane Society US
Non-lethal approaches to cat management	John Boone, Great Basin Bird Observatory
A community perspective on cats in Hawaii	Maka'ala Ka'aumoana, Watershed Community Group, Hawaii

Appendix C - Newspaper Articles published on invasive animals

A selection of newspaper articles published in a recent six month interval (November 2016 – April 2017) reporting on other governmental actions (state, tribal, federal) on invasive animals in or around U.S. national parks. These data are based on a LexisNexis Academic search on 27 April 2017 using the search terms "invasive species" and "national parks", returning 998 reports; 827 from newspapers and 480 from the United States.

Location	Invasive Species	Actor	Action	Source	Date
Colorado	Aquatic invaders	Colorado State Senate	Banned seaplanes from state waters	Denver Post	7-Apr-17
Montana	Aquatic invaders	Salish and Kootenai Tribes	Banned motorized watercraft from tribal waters	Lake County Leader	30-Mar-17
Florida	Burmese pythons	Florida State Senator	Introduced bill to fund professional snake hunters	St Louis Post Dispatch	26-Mar-17
Utah	general	Utah Governor Herbert	In supporting Federal Review of the use of the Antiquities Act, the governor specifically cited federal inattention to pressing issues on federally protected lands naming looters, invasive species and pests as the only examples.	Salt Lake Tribune	10-Feb-17
Minnesota	Aquatic invaders	St. Louis County	Allocated $850,000 to fight aquatic invaders in northern Minnesota (Voyageurs National Park, Isle Royale National Park)	Duluth News Tribune	7-Feb-17
Washington (state)	Feral hog	Washington State Government	Adopted a no tolerance policy to feral swine	Spokesman Review	24-Nov-16

Appendix D - Invasive Species Databases

A partial list of databases that foster information sharing and learning about invasive species.

Information Source	Web Address	Purpose
Early Detection and Distribution Mapping System	(EDDMapS; https://www.eddmaps.org/)	Provide online tools for citizens to report sightings and then map these sightings to detect invasive species distributions
USDA PLANTS database	https://plants.usda.gov/java/	Provides mapping functions for native and non-native plants
Global Biodiversity Information Facility	GBIF, http://www.gbif.org/	Provides mapping functions for species globally
IUCN Global Invasive Species database	ISSG http://www.iucngisd.org/gisd/	Provides distribution, life history and impacts data for invasive species
IUCN Global Register of Introduced and Invasive Species	http://www.griis.org/	Global register of invasive species
BISON	https://bison.usgs.gov/	USGS managed repository for occurrence information
Databasin	https://databasin.org/	NGO managed geospatial data repository containing mapped distribution information, but also case studies of management actions and outcomes

Appendix E - Scientific Names

Africanized bees - *Apis mellifera scutellata*
Asian longhorned beetle - *Anoplophora glabripennis*
Balsam woolly adelgid - *Adelges piceae*
Boa constrictor - *Boa constrictor*
Burmese python - *Python bivittatus*
Burro - *Equus asinus*
Common starling- *Sturnus vulgaris*
Common pigeon - *Columba livia*
Emerald ash borer - *Agrilus planipennis*
Feral hog - *Sus scrofa*
Free-ranging domestic cats - *Felis catus*
Gypsy moth - *Lymantria dispar dispar*
Hawaiian petrel - *Pterodroma sandwichensis*
House sparrow - *Passer domesticus*
Lake trout - *Salvelinus namaycush*
Mosquito - *Culicidae*
Nene goose - *Branta sandvicensis*
Rainbow trout - *Oncorhynchus mykiss*
Red imported fire ant - *Solenopsis invicta*
Red lionfish - *Pterois volitans*
Quagga mussels - *Dreissena bugensis*
Quitobaquito pupfish - *Cyprinodon eremus*
Zebra mussels - *Dreissena polymorpha*

NPS 909/141360, December 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov