SPECIAL ISSUE—INVASIVE SPECIES

PARKSCIENCE

INTEGRATING RESEARCH AND RESOURCE MANAGE
ISSN 0735-9462

ARE WE DOING ENOUGH?

ASSESSING THE INVASIVE PLANT ISSUE

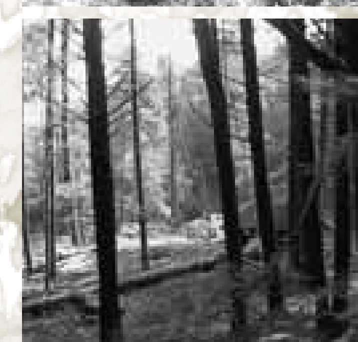
INVASIONS IN THE SEA

HEMLOCK WOOLLY ADELGID AND THE DISINTEGRATION OF EASTERN HEMLOCK FORESTS

ECOLOGICAL EFFECTS OF ANIMAL INTRODUCTIONS AT CHANNEL ISLANDS

IMPACTS OF WEST NILE VIRUS ON WILDLIFE

PLUS, THE CHALLENGE OF PRESERVING NATIVE MUSSEL, SALAMANDER, AND FISH SPECIES



VOLUME 22 • NUMBER 2 • FALL 2004

UNITED STATES DEPARTMENT OF THE INTERIOR NATIONAL PARK SERVICE

From the Guest Editor

INVASIVE SPECIES MANAGEMENT: ARE WE DOING ENOUGH?

Inspiration for this special issue of *Park Science* came from discussions among participants in a workshop to develop guidelines for inventory and monitoring of invasive plants held in Ft. Collins, Colorado, in June 2002. As Lloyd Loope states in the cover article, "Given the seeds of catastrophic loss already planted and those yet to come, invasive species pose a highly significant threat to the biodiversity of the U.S. National Park System in the early decades of the 21st century." The purpose of this issue is to communicate the breadth and depth of the invasive species issue, to document impacts, and to report what has and is being done by the National Park Service and its partners to control this "biological wildfire." This edition also serves as a springboard to discuss the role of the National Park Service in this global issue and to plot a course of action for the future. All articles were solicited to assure that a cross-section of invasive taxa was addressed and that impacts to terrestrial, aquatic, and marine systems were considered.

The cover article by Loope, the "biological wildfire" piece by Tom Stohlgren, and the books reviewed by Pamela Benjamin and Neil Cobb document increasing biological invasions resulting from a breakdown of natural geographical barriers in an age of globalization. They sound the clarion for coordinated efforts in research, education, prevention, control, and restoration that must be components of any action plan to preserve the biodiversity in the National Park System. The NPS Organic Act implies that a key mission of the Service is to protect biodiversity. As Pam Benjamin and I state in our article, we need to place more effort on assessing the distribution, abundance, and impacts of invasive species in the national parks. More importantly, in my opinion, we need to identify those areas of high ecological value that are relatively free of exotic invasives, and make heroic efforts to keep them that way.

Recognition of invasive species as a problem in the National Park System is far from new as Linda Drees, my coeditor for this issue, points out. George Wright noted the negative impacts of nonnative species in the 1930s. Policy against introductions of exotics and control of existing exotics in natural zones dates back to the 1960s. The documentation of resource impacts of feral pigs and brook trout in the Great Smoky Mountains and burros in the Grand Canyon were some of my first exposure to the invasive species issue. Articles in this special issue exemplify the disruption of soils, forests, and wildlife caused by invasive species, and their deleterious effects on marine, aquatic, and terrestrial systems. Kathryn McEachern illustrates the amplitude of impacts of introduced exotics on entire ecosystems. Kyle Merriam and his coauthors investigate how fire management may catalyze exotic plant invasions in some ecosystems.

We certainly have big problems, but we also have some success stories to share. An ambitious program to prevent zebra mussels from migrating into the upper reaches of the St. Croix River has helped preserve the 40 or more species of freshwater mussels in that system. The African oryx has been removed from White Sands National Monument. Leafy spurge is under control as a result of an integrated control program in the Little Missouri River watershed, including Theodore Roosevelt National Park. The National Park Service now has an invasive species coordinator and targeted funding for invasive species management. Exotic Plant Management Teams have treated more than 73,000 infested acres in and around parks.

Are we doing enough? Linda Drees, NPS invasive species coordinator, states that "management of invasive species is in our grasp." I appreciate her optimism, as optimism, good science, adequate funding, and hard work will help us manage invasive species. But we must do more. Battling the likely largest threat to the biodiversity of the National Park System is not a collateral duty.

Ron Hiebert
National Park Service, research coordinator, Colorado Plateau CESU, Flagstaff, Arizona

Editor's Note: Park Science accepts proposals for the development of thematic issues, like this one, to be coordinated by a guest editor. Contact editor Jeff Selleck for further information.

PARKSCIENCE
VOLUME 22 • NUMBER 2 • FALL 2004

DEPARTMENTS

ON THE COVER

Pieces of a mosaic, invasive plant and animal species are transforming the landscape of our national parks, disrupting native species, altering habitats, and compelling science-based control programs. What long-term effects will invaders have on parks, their natural systems, and our enjoyment of these special places? The articles in this special issue delve into many of these troubling questions.

WATERCOLOR—SANTA MONICA MOUNTAINS NRA; BY PHILIP THYS, DENVER SERVICE CENTER, NPS.

COVER ARTICLE

FEATURES

Articles

HIGHLIGHTS

TEAM Leafy Spurge and Theodore Roosevelt National Park:

A PARTNERSHIP FOR THE MANAGEMENT AND CONTROL OF LEAFY SPURGE

TEAM Leafy Spurge, an integrated pest management (IPM) research and demonstration project, is based on the premise that IPM provides the flexibility needed to control agricultural plant and insect pests across broad regions. To demonstrate the effectiveness of the IPM approach for controlling the noxious weed leafy spurge (*Euphorbia esula* L.) over a wide and varied expanse, TEAM Leafy Spurge chose the Little Missouri River drainage, which spans portions of North Dakota, South Dakota, Montana, and Wyoming, as its primary study area because of its complex variety of ecological conditions, all impacted by this invasive plant species (fig. 1). Fortunately, Theodore Roosevelt National Park (North Dakota) occurs within the TEAM Leafy Spurge study area.

Figure 1. About 120 miles (193 km) from Theodore Roosevelt National Park, this landscape in the Missouri River drainage is colored by the yellow bracts of the invasive alien, leafy spurge. The plant displaces native vegetation in prairie habitats.
AGRICULTURAL RESEARCH SERVICE

Figure 2. *Aphthona lacertosa*, flea beetles used in TEAM Leafy Spurge's integrated pest management project, gobble up leafy spurge. Over 15 years, more than 18 million of the beetles have been released within Theodore Roosevelt National Park.
AGRICULTURAL RESEARCH SERVICE

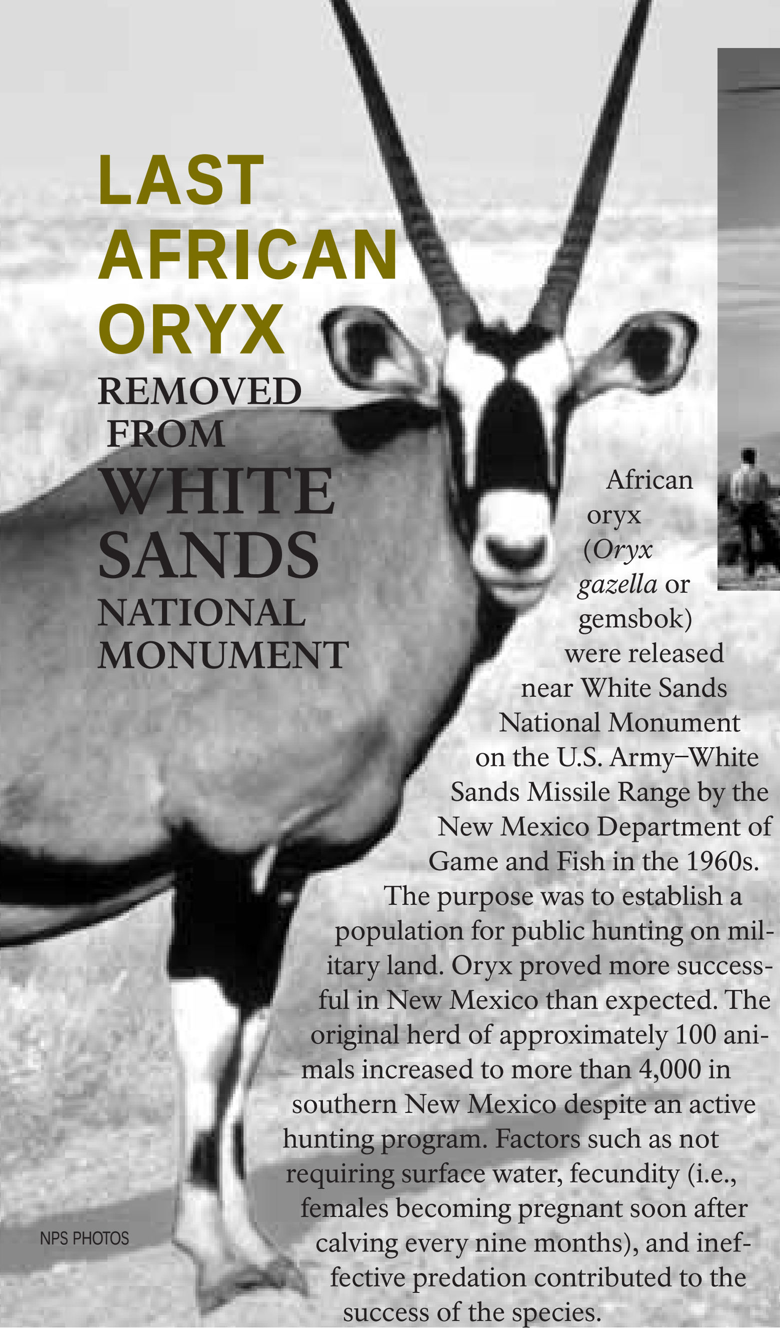
TEAM Leafy Spurge is cochaired and overseen by the USDA Agricultural Research Service in cooperation with the USDA Animal and Plant Health Inspection Service. Together these federal partners make a powerful team to address the leafy spurge problem on a multistate basis. Additional federal bureaus participating in the project are the Bureau of Land Management, USDA Forest Service, National Park Service, Bureau of Indian Affairs, Bureau of Reclamation, and U.S. Geological Survey. State partners are state departments of agriculture and other agencies, cooperative extension services, land grant universities, and county weed managers; private-sector representatives include landowners and ranchers.

Over its six-year life, the project's collaborative emphasis has enabled participants to share resources and expertise, aptly demonstrating how partnerships and teamwork can be used to implement IPM strategies and achieve successful leafy spurge control over broad regions. In particular, the effort has helped demonstrate how *Aphthona* spp. flea beetles can be affordable and sustainable biocontrol agents of leafy spurge in much of the study area (fig. 2), with further containment accomplished through judicious herbicide applications and multispecies grazing.

An instrumental partner in the project was Theodore Roosevelt National Park, a park with serious leafy spurge problems. Over the past 15 years the park has released more than 18 million *Aphthona* flea beetles at 3,534 sites for leafy spurge control. In addition, the park is a strong advocate for the judicious use of herbicides, applied from sprayers attached to backpacks, all-terrain vehicles, and trucks. Helicopter spraying is also conducted in remote backcountry areas. The park has also held numerous field days involving the collection and redistribution of *Aphthona* flea beetles for local farmers and ranchers. This has resulted in a win-win situation for the National Park Service and local communities.

Leafy spurge is a formidable opponent that cannot be controlled or eliminated by any single entity or management practice. Rather, a collaborative, integrated, and regional approach is essential to solving this costly problem. Projects such as the one being conducted at Theodore Roosevelt National Park are using scientifically valid, ecologically based IPM strategies that can achieve effective, affordable, and sustainable leafy spurge control.

C. W. Prosser, ecologist, Theodore Roosevelt National Park, Medora, North Dakota, chad_prosser@nps.gov.



NPS PHOTOS

LAST AFRICAN ORYX REMOVED FROM WHITE SANDS NATIONAL MONUMENT

African oryx (*Oryx gazella* or gemsbok) were released near White Sands National Monument on the U.S. Army–White Sands Missile Range by the New Mexico Department of Game and Fish in the 1960s. The purpose was to establish a population for public hunting on military land. Oryx proved more successful in New Mexico than expected. The original herd of approximately 100 animals increased to more than 4,000 in southern New Mexico despite an active hunting program. Factors such as not requiring surface water, fecundity (i.e., females becoming pregnant soon after calving every nine months), and ineffective predation contributed to the success of the species.

The National Park Service (NPS) completed a 67-mile boundary fence in 1996 to exclude oryx from White Sands National Monument. However, animals contained within the fence increased in population, with concomitant impacts by the 450-pound animals to soil and vegetation. At the time the population was increasing at a rate of 20 to 30% per year; if left uncontrolled the situation would have caused severe resource degradation. Removing the oryx from NPS land was complicated by the lack of roads in the 144,000-acre (58,320-ha) monument and the oryx's habit of disbursing widely over the desert.

A draft environmental assessment was prepared in 1998, presenting the preferred alternative of NPS staff shooting the estimated 140 to 190 animals. Thereafter, a critical news article resulted in an organized letter-writing campaign with 161 respondents from coast to coast objecting to the proposed management action.

As a result of public input, oryx removal plans shifted to more expensive and dangerous nonlethal management methods. These included the use of helicopters and all-terrain vehicles for herding oryx to openings in the fence, and also shooting them with anesthesia-filled darts followed by loading the drugged animals in a sling attached to a helicopter for transport out of the monument. Park staff and partners tried constructing one-way gates in the boundary fence that would allow the animals to leave the monument, but the attempt was not successful. Contraceptive drug darting to prevent further expansion of the population was not considered feasible.

Several partners assisted monument staff in carrying out the helicopter sling-loading operation over several years. They included the NPS Biological Resource Management Division, Carlsbad Caverns and Mesa Verde National Parks, New Mexico Department of Game and Fish, U.S. Army–White Sands Missile Range, and the U.S. Fish and Wildlife Service. Funding for the operation came from the Natural Resource Preservation Program and the Recreational Fee Demonstration Program.

The initial herding and sling-loading operation was effective, resulting in the removal by nonlethal means of 174 oryx from White Sand National Monument from 1999 to 2001. Nevertheless, helicopter search time to locate oryx increased greatly as the animals became scarcer, and the cost per animal escalated. Subsequently, the National Park Service publicly released an environmental assessment in November 2001 recommending complete removal of the relatively few remaining oryx by lethal means, with support of the New Mexico Department of Game and Fish. The monument received 39 letters supporting the project and 9 that either opposed it or confused it with other management issues, and the National Park Service signed a "Finding of No Significant Impact" to begin the final phase of control.

The project was well covered by regional media, as well as the *Wall Street Journal* and *High Country News*. Twenty-five animals have been shot to date and no fresh sign has been detected, suggesting that oryx no longer roam within the fenced portion of White Sands National Monument. Long-term, annual maintenance by tracking and shooting (if any oryx are detected) is planned, as is maintaining the 67-mile fence indefinitely.

Bill Conrod, biologist, White Sands National Monument, New Mexico; bill_conrod@nps.gov.

Information Crossfile

The costs of invasion

Resource managers face the difficult task of picking and choosing which ecological problems, among many, they can actively address. In a crisis-laden field, how can we prioritize resource needs? Where do invasive species rate among the myriad threats facing the National Park System? Two frequently cited articles provide justification for moving invasive species management near the top of the list. A 1998 study of threatened and endangered species in the United States found that alien species are second only to habitat destruction and degradation as a threat to imperiled species (Wilcove et al. 1998). The authors quantify threats to imperiled species in the United States. In summation, exotics affected 57% of plant species and 39% of animal species analyzed overall, and the figures jump to nearly 100% when considering only Hawaiian species. Investigators also found that invasive species affect aquatic systems in the West in particular.

In addition, Pimental and others (2000) tally the economic costs of biotic invasions at approximately $137 billion annually in the United States alone. In the article “Environmental and Economic Costs of Nonindigenous Species in the United States,” the authors combine the losses and damages caused by alien invasive species with the costs of control for exotic plants, vertebrates, invertebrates, and microbes to obtain a rough estimate of the total cost. Often no data concerning the costs of an invasion were available; therefore, the true cost of invasive species almost certainly is underestimated in this study. However, information from these two studies shows that allocating funds to invasive species management projects has both high economic and ecological value. —R. Harms, graduate student, College of Environmental Science and Education, Northern Arizona University, Flagstaff.

References

Pimental, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50(1):53–65.

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48(8):607–615.

Trade policy and prevention of nonnative species invasions

Approximately half of the invertebrate and disease pests imported into the United States come in on live plants; most of the other half of pests comes in on raw wood and wood packaging. Quantities of these items are increasing with increasing trade. Horticultural imports are not only risky because of the small (1–2%) but highly significant numbers of invasive exotics that escape, but also because of the hitchhikers on these imports. Because biological invasions are rarely reversible, prevention seems desirable. However, the current process in the United States and most other countries is to try to balance native biodiversity protection and trade promotion. The rules established by the United States and its trading partners are based on the premise that phytosanitary regulations should not be more restrictive than necessary to achieve a country’s chosen level of protection. Furthermore, the World Trade Organization regards phytosanitary measures as a potentially unjustified barrier to free trade. Therefore, the burden of proof is placed on advocates for the prevention of exotic species invasions and the protection of native biodiversity.

Recent articles detailing the major pathways of pests entering the United States may be useful for resource managers in achieving a broad understanding of invasions and options for improvement in U.S. strategy, policy, and techniques for prevention. Campbell (2001) examines U.S. and international policies governing the structure and implementation of invasive species prevention programs, and recommends approaches for addressing the huge consequent problems that arise for protection of biodiversity. Campbell and Schlarbaum (2002) provide much detail on the biological outcome of prioritizing trade above protection—which results in forests, especially those of eastern United States, dying because of introductions of damaging foreign pests and diseases. Campbell and Kriesch (2003) review and outline pathways for invasive species into the United States. —L. Loope, Haleakala Field Station, USGS, Pacific Island Ecosystems Research Center, Maui.

References

Campbell, F. C. 2001. The science of risk assessment for phytosanitary regulation and the impact of changing trade regulations. BioScience 51(2):148–153.

Campbell, F., and P. Kriesch. 2003. Invasive Species Pathways Team. Final report. Available at www.invasivespecies.gov/council/pathways.doc (accessed 1 June 2004).

Campbell, F. C., and S. E. Schlarbaum. 2002. Fading forests II: trading away North America's natural heritage. Healing Stones Foundation, Smithville, Tennessee; American Lands Alliance, Washington, D.C.; and the University of Tennessee, Knoxville. Available at http://www.americanlands.org/new_page_21.htm (accessed 1 March 2004).

Before and after eradication: considering the ecosystem effects of invasive species

Most land managers in the National Park Service view the removal of invasive exotic species from natural landscapes as a top priority. However, as invasive species become pervasive elements of the communities they invade, their relationships and interactions with native species become established and complex. In the article "Viewing Invasive Species Removal in a Whole-Ecosystem Context," the authors urge a careful analysis of invaded systems before removing a species.

Eradication projects can have unintended consequences on native systems. For instance, the removal of feral herbivores at Santa Cruz Island (Channel Islands National Park, California) led to an increase in fennel *(Foeniculum vulgare)*, starthistle *(Centaurea solstitialis)*, and other introduced herbs (see note following). Likewise, removing exotic prey can cause exotic predators to switch to native prey for food, as happened in New Zealand when exotic stoats (ermine *[Mustela erminea]*) increased predation on native birds and mammals after rats and possums were removed from forests. Native species also can come to rely on exotic species; for example, endangered Southwest willow flycatchers *(Empidonax traillii extimus)* often nest in thickets of invasive, nonnative tamarisk (*Tamarix* spp.).

Eradication projects can have unintended consequences on native systems.

To avoid unanticipated, "surprise" outcomes, the authors suggest that assessment precede eradication. Specifically, food-web interactions among exotics and between exotics and natives should be investigated, and functional roles of invasive species should be identified. In addition, post-eradication monitoring should be included in a program to determine the effects of management actions on both the targeted species and the affected ecosystem. By incorporating these processes into management plans before and after eradication, an informed framework can guide invasive species management and ecosystem restoration. —R. Harms, J. Selleck, and K. Faulkner (Channel Islands National Park)

Reference

Zavaleta, E., R. Hobbs, and H. Mooney. 2001. Viewing invasive species removal in a whole-ecosystem context. Trends in Ecology and Evolution 16(8):454–459.

Editor's note: As the authors note, the removal of sheep and cattle from Santa Cruz Island led to the recovery of native Bishop pine *(Pinus muricata)*, but also to an apparent increase in the distribution and abundance of other rare plant species. (Klinger, R. C., et al. 1994. Vegetation response to the removal of feral sheep from Santa Cruz Island. Pages 341–350 in W. L. Halvorson and G. J. Maender, editors. The Fourth California Islands Symposium: Update on the Status of Resources. Santa Barbara Museum of Natural History, California.)

Theory guides rapid response to plant invasions

Land managers have long realized that exotic species do not invade plant communities equally. Many theories have been advanced to explain these differences, but studies to investigate these theories often produce conflicting or ambiguous results. However, Davis and others (2000) have developed a new theory from empirical studies and long-term vegetation monitoring that is simple yet captivating: a plant community becomes more susceptible to invasion whenever an increase in the amount of unused resources occurs. This increase may come about through a reduction in resident vegetation (e.g., from heavy grazing, a disease outbreak, or intense flooding) or through an increase in the resource supply (e.g., during a particularly wet year or as a consequence of eutrophication). A community's susceptibility to invasion, therefore, varies over time. These pulses of resource availability also must coincide with the presence of invasive propagules such as seeds and spores, leading to the episodic establishment of invasive species.

A plant community becomes more susceptible to invasion whenever an increase in the amount of unused resources occurs.

This theory has important implications for resource managers, in particular the required response to new invasions. In short, environments that are naturally subject to frequent fluctuations in resource availability will be invaded most often and should be a priority for monitoring and potential mitigation. Areas that experience a known disturbance or influx of resources also should be investigated. —R. Harms

Reference

Davis, M. A., J. P. Grime, and K. Thompson. 2000. Fluctuating resources in plant communities: a general theory of invasibility. Journal of Ecology 88:528–534.

Exotic plants and restoration

The differing impacts of exotics can be confusing because exotic species pose both problems and solutions. For example, exotic species can colonize disturbed lands and alter sites targeted for restoration. On the other hand, exotic species can catalyze the restoration process and be used to reestablish site functions if native species are not available or cannot tolerate current conditions. Because of this ambiguity, researchers and practitioners should look to both the scientific literature and previous restoration projects when determining the best approach for restoring a particular site.

Before beginning a restoration project, managers should identify likely plant invaders and devise strategies to minimize their impacts. The method of removing exotics also should be considered carefully because sensitive species may affect what managers can and cannot do at a site. In addition, some sites will require continuous maintenance, so long-term management costs should be evaluated. Moreover, various exotic species continue to affect sites after their removal; the reversibility of these conditions and the impacts on restoration warrant further study. In some cases, intermediate plantings of species assemblages may be needed to move the site toward conditions that support the desired flora. These intermediate assemblages may need to include certain exotic species if native species cannot survive the current conditions at the restoration site. These exotics should be selected with an emphasis on their inability to persist in the system after they have served their primary function in the restoration process. Projects also should include long-term monitoring to determine whether management goals are being achieved.

Managers must be broad-thinking about exotic plants as both friend and foe.

Managers must be broad-thinking about exotic plants as both friend and foe. Nevertheless, when considering possible responses to their planned activities, resource managers must be prepared to react quickly to surprises from ambiguous exotic plants. —R. Harms

Reference

D'Antonio, C., and L. A. Meyerson. 2002. Exotic plant species as problems and solutions in ecological restoration: a synthesis. Restoration Ecology 10(4):703–713.

A web site for teachers

Web sites about invasive species abound on the Internet. Teachers will welcome one of them, http://www.nps.gov/invspcurr/alienhome.htm, that presents engaging units on the theme of invasive species for middle school classes. "Aliens in Your Neighborhood" was developed as an enhancement to required curriculum about the life sciences, especially plant science. Activities provide opportunities for students to practice math, writing, mapping, photography, and collecting and preserving plant specimens. These lessons lead students to see more closely what's going on in their immediate environment. For example, with woolly socks worn over their shoes, they take a walk at the edge of a forest or field. Then they examine the seeds stuck to the socks and understand how easily seeds are dispersed. Students plant a small piece of their sock in soil and watch what grows. This leads to investigation in many directions, such as how to identify the seedlings, how well the native species are competing with the exotics, how to reduce dispersal, and so on.

The project is sponsored by the National Park Service, funded by the Parks as Classrooms program, with additional support from the Cooperative Ecosystem Studies Unit of the University of Idaho; Washington Department of Fish and Wildlife NatureMapping Program; XID™ Services, Inc.; and CyberTracker World GIS Mapping Technologies. The author is Mark Goddard of the Nye Beach Montessori School in Newport, Oregon. Because the natural resource managers understand that invasive species are everywhere, they look to citizen scientists to help in containing the invaders. The lessons in these units are the foundation of the education of enlightened citizen scientists and, very likely, of some future professional scientists. —B. Blumberg

What's the big deal about earthworms?

We assume that earthworms are good for our gardens and soil. But consider the natural ecosystems in the National Park System, for example national parks in the upper Midwest. Recently researchers have reported in various articles that invasive, exotic earthworms from Europe and Asia (e.g., *Lumbricus rubellus*) can have a deleterious impact on the forest floors of northern temperate forests.

The most dramatic effect of earthworm invasion is the loss of the forest floor at previously undisturbed sites.

See "Information Crossfile" in right column on page 31

BOOK REVIEW

NATURE OUT OF PLACE:
Biological Invasions in the Global Age

By Jason Van Driesche and Roy Van Driesche

A Book Review by Pamela K. Benjamin

Nature Out of Place carries an unwavering message throughout: invasive species management has been, and for the most part remains, essentially reactive. However, the son and father team of Jason and Roy Van Driesche avoid the typical "doomed" vision of invasive species management. Instead the authors lead the reader progressively away from the most extreme problems toward public involvement and hopeful solutions. This well-written book distinctly and clearly identifies the ecological, cultural, and political complexities of the invasive species issue. Geared toward a general audience, *Nature Out of Place* serves as an excellent, nontechnical reference, providing a wealth of information related to the history, ecology, and urgency needed in addressing biological invasions.

***Nature Out of Place* serves as an excellent, nontechnical reference, providing a wealth of information related to the history, ecology, and urgency needed in addressing biological invasions.**

COPYRIGHT ISLAND PRESS

The book is separated into three parts. Part one focuses on the scope and history of the invasive species issue. Part two examines the ecological consequences of and the human responses to nonnative invasions. Part three shifts the focus to public awareness and suggestions for what everyday people can do about biological invasions. Each part of the book provides specific case studies (written in first person) followed by background essay-style chapters designed to provide the reader with more depth and knowledge of issues raised in the case studies. Jason Van Driesche, a graduate student at the University of Wisconsin, takes the readers on a personal journey to the "front lines," providing firsthand interviews with field scientists and land managers. Roy Van Driesche, a University of Massachusetts professor and biological control researcher, provides the scientific background.

The authors provide an insightful overview of the dramatic transformations that human culture and commerce (transportation technology) have brought to native habitats throughout the world….

Chapter one begins with a case study of feral pigs and the conversion and loss of native forests in Hawaii. The authors deliver a superb overview of this issue and eloquently lead the reader through the mire of direct and indirect impacts created by this species, including facilitating the establishment of additional nonnative species. This chapter highlights the complexity of dilemmas faced by land managers in battling biological invasions, but the authors do not stop here. Additional chapters detail zebra mussel invasion in the Ohio River basin, decades of leafy spurge presence on the northern Great Plains, woolly adelgid invasion and the loss of eastern hemlock forest, the devastation of beech bark disease, the dramatic loss of the American chestnut, the current threat of the Asian longhorned beetle, and the impacts of sheep on Santa Cruz Island at Channel Islands National Park.

How did these biological invasions happen and why do they remain such a worldwide threat? The authors provide an insightful overview of the dramatic transformations that human culture and commerce (transportation technology) have brought to native habitats throughout the world, starting with foot travel, to the age of the sail, to development of mechanized travel, and ending with the "homogenizing of the planet" in the modern age of globalization. This unique and objective summary cannot help but leave the reader contemplating the realities of globalization and the fact that "For the first time in history, it is laws and good judgment—not cargo space or speed—that [will] serve as constraints on species translocations."

The middle section of the book (chapters 4–11) explores the larger themes that frame the issues identified within the case studies: What are the characteristics of effective invaders? What makes native ecosystems vulnerable to invasion? What are the ecological consequences of invasive species? How have we responded as a society to the threats presented by biological invasions? This section of the book provides the reader with a good (although at times over-generalized), nontechnical synopsis of many complex ecological issues. Despite some ecological shortcomings (and a bias for the use of biological control), the authors do an exemplary job of introducing the reader to the "bigger picture" concepts: (1) thinking about ecosystem degradation and biological invasions holistically (the presence of invasive species is as often symptomatic as it is a direct cause), (2) thinking about risk in a biological (not just an economical) context, (3) identifying active prevention measures to limit the unintentional movement of invasive species, and (4) developing a stronger legal framework and policies for prevention. The take-home message for this section of the book is extremely important and indisputable—"More effective *prevention* methods have to become an integral part of how society works while there are still invasions to prevent."

The final section of the book brings the issue of biological invasions home to the reader and is entitled "Going local in the global age." Whether forming or participating in invasive species action committees, restoring "nature" in an urban environment, or simply landscaping our homes with native plants, the authors remind us that there is hope and that we (the public), through our actions and our informed judgments, are the solution to the issue of biological invasions.

This book is a "must read" for anyone involved with the management, protection, or interpretation of natural lands! *Nature Out of Place* is an effective tool for increasing public understanding and awareness of the invasive species problem.

Pamela K. Benjamin is a vegetation ecologist for the NPS Intermountain Regional Office; P.O. Box 25287; Denver, CO 80228. Her e-mail address is pamela_benjamin@nps.gov.

Nature Out of Place:
Biological Invasions in the Global Age
Copyright 2000
Island Press, Washington, D.C., and Covelo, California
ISBN 1-55963-757-9; 363 pages

A PLAGUE of RATS and RUBBERVINES

The Growing Threat of Species Invasion

By Yvonne Baskin

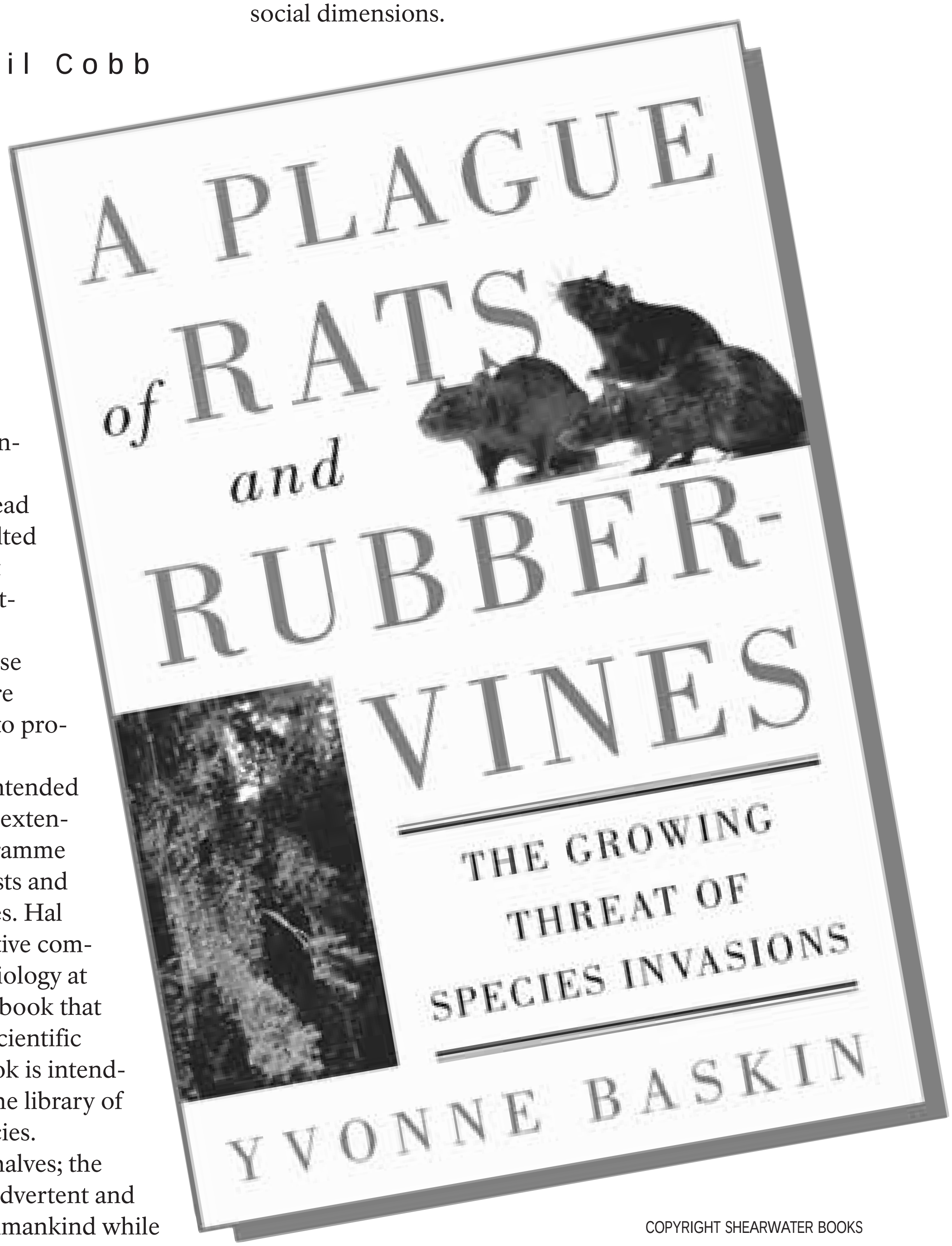
A book review by Neil Cobb

Welcome to the Monogocene, a new geologic epoch characterized by "sameness or monotony," whereby the distribution of biota are determined by the activities of humans via invasive species. The Monogocene is a facetious term suggested by Gordian Orians, which underscores the central role of human activity in determining global biodiversity. Specifically, our direct or indirect involvement in the spread of species throughout the globe has resulted in a large number of invasive exotics that will eventually determine biodiversity patterns on Earth. Baskin's book warns us against the Monogence by making the case against invasives. She also makes the more important case for reasonable solutions to protect native plants and animals.

Baskin states clearly that this book is intended to reach beyond scientists. It is partly an extension of the Global Invasive Species Programme (GISP), a partnership network of scientists and technical experts on invasive alien species. Hal Mooney, chairperson of the GISP executive committee and professor of environmental biology at Stanford University, wanted to publish a book that would reach a larger audience than the scientific community that launched GISP. This book is intended for the public and should be part of the library of anyone who is interested in invasive species.

The book is divided roughly into two halves; the first half provides descriptions of the inadvertent and purposeful introduction of species by humankind while the second half is devoted to a search for solutions. Baskin provides an abbreviated list of examples of introduced species and spends a good portion of the book to discussing ways we can slow down the spread of invasives and mitigate the impacts from species that are a permanent part of our landscapes. I say abbreviated because one could write volumes about all the documented cases of invasives that have impacted different regions of the globe.

I enjoyed the way the book moves from descriptions of personal experiences to the larger context of the particular topic, with enough facts to educate readers but not overwhelm them. With each chapter there is a nice transition from the narratives to provisions of concise lists of facts about ecology, economics, and social dimensions.



Stories of personal travels around the globe provided nice intervening vignettes. I took pleasure in her novel-like descriptions of encounters with invasive species; I felt like I was reading *Jurassic Park* over again, but rather than a velociraptor appearing at the end of a paragraph, there was an insidious new invasive species.

Her book covers disease organisms as exotic species, an important category to emphasize and one that most people do not think of as invasive. The recent epidemic of SARS (severe acute respiratory syndrome) really drives this point home and underscores the reality that with millions of people traveling daily across the globe, the potential for introducing devastating invasives overnight is very high. For those who do not appreciate the impact of something like cheatgrass, an invasive annual grass affecting western North America, disease organisms more directly deliver the message. Many of the invasions go unnoticed because the native species they eliminate do not capture newspaper headlines. That is the sad part of this story: if invasives eliminate unfamiliar species we do nothing. Because so many species have yet to be scientifically described, we will never know the full impact of invasives on the landscape.

Her book covers disease organisms as exotic species, an important category to emphasize and one that most people do not think of as invasive.

The book provides an important historical perspective, a reminder that human activities have been spreading species for thousands of years. We have always tended to bring familiar animals and plants, or those that sustain us like crop plants, with us as we move about. Today millions of people moving about daily serve as potential agents of dispersal. Despite our awareness of the problems that come with introduced exotics, the increased connectedness of our global economy will strain our ability to prevent the spread of unwanted species.

The increased connectedness of our global economy will strain our ability to prevent the spread of unwanted species.

Baskin's critical review of the role of the United States government in protecting native species from invasives is timely and poignant. She argues that the government has been lax in confronting the threat of invasive species despite the body of scientific evidence that suggests invasives have a tremendous negative effect on public and private lands, at great cost to the U.S. economy. She also notes that the United States was one of the few countries that did not ratify the 1992 biodiversity treaty.

Any author dealing with invasive species has a daunting task of formulating a realistic plan of action to mitigate the negative effects of invasives. I respect Baskin's pragmatic assessment of the situation, realizing that we must choose our battles carefully in this war against unwanted species. As a group, invasives are here to stay, but there are ways in which we can realistically protect native biota. I find it encouraging to consider a realistic plan of action, and the book is careful not to overestimate the possibilities for protecting native biota. I appreciated the constant but subtle theme of saving native biota as the goal rather than the unrealistic goal of eliminating exotics.

We must choose our battles carefully in this war against unwanted species.

Reading a book about invasive species is always difficult for me because the problem seems so overwhelming. This book shared a nice mix of caution and hope that I found comforting but honest. Overall the book is very successful as a nontechnical work for the layperson or scientist and is enjoyable to read.

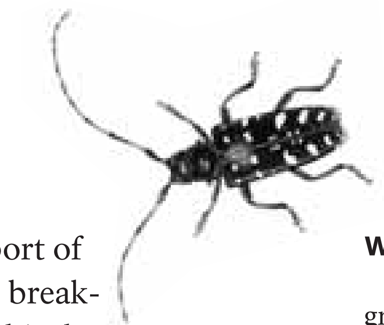
About the author

Neil Cobb is director of the Merriam-Powell Center for Environmental Research and the curator of the Colorado Plateau Museum of Arthropod Biodiversity, Department of Biological Sciences, at Northern Arizona University in Flagstaff, Arizona. He can be reached at Neil.Cobb@nau.edu.

A Plague of Rats and Rubbervines:
The Growing Threat of Species Invasions
Copyright 2003
Shearwater Books
ISBN 1559630515; 371 pages

THE CHALLENGE OF EFFECTIVELY ADDRESSING THE THREAT OF INVASIVE SPECIES TO THE NATIONAL PARK SYSTEM

By Lloyd Loope



Ever-increasing transport of species of all kinds is breaking down biogeographical boundaries with profound consequences for biodiversity loss worldwide (Vitousek et al. 1997, Mooney and Hobbs 2000). When species are transported—intentionally or inadvertently—outside their original geographic ranges, many of them become established and spread. Some proliferate explosively, tending to displace native species in their new area of establishment. Evolving technology (e.g., containers) has increased shipping speeds and volumes, making our detection and interception strategies for stemming the flow of invasives in the United States very difficult to implement and certainly inadequate (Campbell 2001; Loope and Howarth 2003) (fig. 1). Given the seeds of catastrophic loss already planted and those yet to come, invasive species pose a highly significant threat to the biodiversity of the U.S. National Park System in the early decades of the 21st century (e.g., Wilcove et al. 1998). Moreover, global climate change is likely to exacerbate the problem by favoring invasive nonnative species over native species (Mooney and Hobbs 2000). Writing as a former (24 years) employee of the National Park Service, now with the U.S. Geological Survey (USGS), my attempt here is at a personal review and synthesis of implications of trends in biological invasions for national parks, based on personal experience and analyses by others.

WHO WILL PREVENT AND COMBAT INVASIONS?

Invasive plants comprise a highly visible taxonomic group among many serious biological invaders permeating the United States and reaching even the relatively isolated and intact ecosystems of the national parks. Federal natural resource managers can potentially address invasive species issues in conjunction with local outreach efforts, working with agencies (federal, state, and local) and individuals in communities surrounding the parks and refuges for education, prevention, detection, and rapid response.

An NPS workshop in Ft. Collins, Colorado, 4–6 June 2002, in which I participated, produced useful guidelines for monitoring invasive plants in and near the national parks (Hiebert and others 2002). Noteworthy innovations of the guidelines include the need to "work outside of park boundaries to manage at a landscape scale … [and] identify a buffer zone, which, when adequately managed in cooperation with partners, will more effectively accomplish invasive species management goals." Yet, although increasing attention is being given by public and private entities to the need for controlling plant inva-

Figure 1. Containers arrive at the Port of Auckland, New Zealand. The New Zealand Ministry of Agriculture and Forestry (www.maf.govt.nz) is at the forefront of exploring techniques for reducing the risk of pest introduction via the burgeoning sea and air container traffic, a primary factor leading to rampant biological invasions worldwide. USGS PHOTO BY PHILIP THOMAS; INSECT ILLUSTRATION—USDA FOREST SERVICE

sions, almost no barriers to the movement of plant species by humans throughout the world exist, including the United States. Approximately 20,000 species of vascular plants have proved invasive and damaging somewhere in the world (Randall 2002). U.S. federal noxious weed law (APHIS 2000) currently prohibits 91 species and five genera, most of which are well-documented threats to agriculture.

Almost no barriers to the movement of plant species by humans throughout the world exist....

Other taxonomic groups besides vascular plants pose present and even greater future threats to park ecosystems. Insects and fungal diseases that attack trees are probably the most important groups nationwide. The Forest Service began working with the Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture (USDA) in the late 1980s to address invasive species threats associated with raw wood imports and solid-wood packaging materials (e.g., Tkacz et al. 1998). Nevertheless, Thomas Hofacker (staff entomologist, USDA Forest Service) sees forest health in the United States as broadly declining, with three to five new problematic insects or pathogens becoming established in this country each year, and with many tree species becoming "functionally extinct" (presentation at annual meeting of Entomological Society of America, San Diego, CA, December, 2001). Campbell (2001) believes this situation is at least partly because the international system for regulating trade to prevent transport of potentially harmful organisms places a huge burden of proof on countries wanting to protect their ecosystems from pests arriving through such pathways as raw wood and wood packing materials. Another important point is that the national and international quarantine system was designed to protect mainstream agriculture with little or no reference to the protection of natural areas from biological invasions (Campbell 2001, Baskin 2002).

In the United States, the agency primarily responsible for protecting our nation's borders from biological invasions was until recently USDA-APHIS. Because of growing recognition of the need to address this problem (e.g., the threat to forests of insects and diseases in raw wood and wood packaging material) and others, APHIS had begun to focus beyond its primary mandate of protecting mainstream American agriculture. Most of the large branch of APHIS responsible for protecting our borders from biological invasions at U.S. ports of entry (Plant Protection and Quarantine) was transferred to the Department of Homeland Security (DHS) in March 2003. How this move to a different government department with a different mandate will affect the protection of natural areas and biodiversity is not clear.

A 1993 report by the Congressional Office of Technology Assessment recognized many challenges the existing system faces to keep harmful nonindigenous species out of the United States (OTA 1993). For example, first-class mail within this country is a virtually unaddressed major pathway for transport of biological material (potentially, for example, federal noxious weeds), protected against "unreasonable searches" by the Fourth Amendment to the U.S. Constitution (OTA 1993, p. 48–49). This is just one of many cases cited in the OTA report in which the current system gives invaders the edge.

Since publication of the OTA report, international treaties to facilitate the workings of the multilateral trading system have evolved (Werksman 2004). After years of trade negotiations, the World Trade Organization was established in 1995 and with it a treaty on sanitary and phytosanitary measures (FAO 2004). The treaty is managed by the Food and Agriculture Organization of the United Nations, which is responsible for implementing the International Plant Protection Convention. Some of the trade-promotion measures have not benefited invasive species prevention. For example, countries cannot legally exclude a potential pest in commerce unless they can clearly establish that a specific, credible threat exists through a risk-assessment process. Moreover, a country can require *only the minimum* treatment measures documented as effective in reducing risk. On the positive side, it can be said that the international system has responded well to the threat of movement of pests in solid-wood packaging material and has produced largely excellent guidelines for regulating this pathway (FAO 2002)

BIOLOGICAL ASYMMETRY AND INVASIONS

Not all regions of the world are equally susceptible to biological invasions; some regions primarily seem to be source areas. Called biogeographic asymmetry, this phenomenon has been widely recognized in marine and aquatic invasions (Vermeij 1991, Lodge 1993) although it is just as prevalent in terrestrial invasions. North American forests are particularly vulnerable to invasions of European and Asian insects (North American Forest Commission 2000) (fig. 2). Many more plant-eating forest insects from Europe have successfully invaded North America (approximately 300) than have invaded Europe from North America (34) (Nemiela and Mattson 1996). The decline of forest species of eastern North America caused by insects and pathogens, mainly from Asia (Campbell and Schlarbaum 2002), does not seem to be a reciprocal phenomenon. Very few native insects and diseases of North America are known to have become established in Asian forests.

HAWAII—THE U.S. REGION MOST SUSCEPTIBLE TO BIOLOGICAL INVASIONS

Oceanic islands are well known to be especially vulnerable to invasive species. The Hawaiian Islands comprise one of the most isolated island groups in the world, with biological endemism at the species level approaching 100% for many native groups. Over all, Hawaii has approximately 10,000 endemic species (found nowhere else on Earth besides Hawaii), out of a total biota of approximately 20,000 native species (Eldredge and Evenhuis 2003). Hawaii, with far above-average vulnerability to invasions (Loope and Mueller-Dombois 1989), is also a major international hub of commerce. It is by far the U.S. region most damaged by invasions, with large numbers of and serious impacts from invasive vertebrates, invertebrates, and flowering plants (e.g., Loope 1998).

Figure 2. The destructive Asian longhorned beetle *(Anoplophora glabripennis)* from China provided a wake-up call regarding the threat of solid-wood packaging material as a major pathway for invasive pests into the United States. After being intercepted repeatedly at ports of entry for several years by border protection quarantine officials, a population was discovered in Chicago in 1998. USDA FOREST SERVICE

Nevertheless, Hawaii receives no special protection to prevent invasive species introductions. Border protection from foreign passengers' baggage and cargo at the Port of Honolulu is essentially identical to that at all other international ports in the United States (CFR, Chapter 7, 319.56-8). Preventive actions are taken based primarily on an approved list of organisms for which specific legal authority is deemed to exist (James Kosciuk, Agriculture Liaison, Customs and Border Protection, DHS, Honolulu, Hawaii, personal communication, May 2004). Moreover, although Hawaii has better laws for preventing invasive species establishment than most states (OTA 1993), the Hawaii Department of Agriculture has little or no authority for protection from pests from foreign sources and receives limited funding (HDOA 2002). USDA-APHIS has a large program based in Hawaii for airport departure inspections to protect mainstream agriculture on the U.S. mainland from Hawaii's pests but no reciprocal measures for protecting Hawaii (OTA 1993). Clearly, the quarantine system is not protecting Hawaii from what Bright (1999) termed the "pathogens of globalization."

Hawaii has been one of the most unfortunate locations in the world as far as pest introduction is concerned, and its biodiversity and agriculture have suffered. The state is in the midst of an invasive species crisis affecting not only the archipelago's highly endemic biota, but also overall environmental and human health, and viability of its tourism- and agriculture-based economy (CGAPS 1996). The Invasive Species Specialist Group of the World Conservation Union (i.e., IUCN) recently developed a list of "100 of the World's Worst Invasive Species" (ISSG 2002); Hawaii has 47 of them.

Hawaii has roughly the same total number of nonnative arthropod species as the continental United States. McGregor (1973) speculated on the reason: "Although there is much greater diversity of crops and habitats within the continental United States, these are dispersed over a vastly larger land area. In Hawaii, where the overall diversity is less, the various habitats are more readily accessible from the principal port of entry." The more moderate and stable climate of Hawaii is also more favorable to an invading species than the climate in much of the United States. Furthermore, McGregor (1973) recognized this point in relation to agricultural quarantine: "(for insects and mites) in the period 1942–72 the rate of colonization per thousand square miles was 40 species, 500 times the rate of [the] continental United States." There is no evidence to indicate that this pattern has changed in the following 30 years.

More native species have been eliminated in Hawaii than anywhere else in the United States. Hawaii has lost about 8% of its native plant species and an additional 29% are at risk (Loope 1998). The state has lost 27 of its 73 historically known bird species and about 900 of 1,263 described land snail species (Loope 1998). With just

0.2% of the U.S. land area, Hawaii has about 30% of U.S. endangered species. Although habitat destruction has been an important cause of extinction and endangerment, the introduction and spread of invasive alien species has contributed in a major way in the past and is now the predominant cause of biodiversity loss in Hawaii.

With just 0.2% of the U.S. land area, Hawaii has about 30% of U.S. endangered species.

Still, much biological richness is left in Hawaii's national parks, mostly at high elevations, but what is left is threatened by old, new, and future invasions. The invasive tree *Miconia calvescens* is an alarming and imminent threat (fig. 3). This large-leaved, shade-tolerant tree from tropical America has greatly reduced biodiversity over most of the rain forest area of Tahiti (Meyer 1996, Meyer and Florence 1996) and promises to do the same in Hawaii without major management intervention. Hawaii's national parks and Hawaii's NPS Exotic Plant Management Team are very much involved in interagency efforts to manage *M. calvescens* (e.g., Loope and Reeser 2001).

Figure 3. Biologist Jean-Yves Meyer stands beneath a typical forest of the invasive tree Miconia calvescens in Tahiti. Miconia has become recognized as an invader capable of extinguishing biodiversity in island rainforests, and is being aggressively combated by the Hawaii Exotic Plant Management Team and others in Hawaii. PHOTO COURTESY OF JEAN-FRANÇOIS BUTAUD AND JEAN-YVES MEYER, 2004.

Good models for improved prevention for Hawaii exist in the largely successful preventive systems in place in New Zealand and Australia. In these countries the public accepts laws and procedures, some involving a small loss of personal freedom, as the price that must be paid for protecting agriculture, forests, and native ecosystems. New Zealand has comprehensive biosecurity legislation and a highly rigorous border control system, utilizing trained dogs and X-ray technology (Baskin 2002, Loope 2004). Australia has a relatively successful plant screening system that has evaluated thousands of new plant introductions since its inception (Pheloung et al. 1999, Baskin 2002).

The stakes are high in Hawaii because of the state's world-class biota. No location in the world rivals Hawaii as a showcase for biotic evolution in isolation and adaptive radiation—not even the famed Galapagos archipelago (Williamson 1981). In Hawaii, the National Park Service emerged as a leader in conservation biology about 1970, turning apathy into action, and showed that extensive native ecosystems persisted at high elevations in the state. It has pioneered the use of fencing as a tool for sustained elimination of feral ungulates (Stone and Loope 1996), serious alien plant control within designated "special ecological areas" (Tunison and Stone 1992), pushing for better quarantine measures at airports and harbors (Reeser 2001), and drawing the line against *Miconia* and other invasive species. The National Park Service in Hawaii is well aware that it cannot rest on its laurels, however (Bryan Harry, NPS Pacific area director, personal communication, 2004).

The National Park Service in Hawaii is well aware that it cannot rest on its laurels....

LAG TIME OFTEN MASKS BIOLOGICAL INVASIONS ON THE U.S. MAINLAND

Given unabated action of similar forces responsible for continued ecological degradation—habitat destruction and fragmentation, biological invasion, and cascading effects—biodiversity of mainland national parks is clearly at risk (Vitousek et al. 1997). Meanwhile, Hawaii comprises a useful testing ground where strategies to prevent and combat invasions can be applied, tested, and refined.

Lag time is an important and underappreciated phenomenon in invasion biology and tends to mask the pervasiveness of invasive species on the North American continent. For example, very many nonnative insect and disease problems in eastern North America went unnoticed initially but have gathered momentum and become acutely problematic with time. For example, white pine blister rust (*Cronartium ribicola*), introduced with nursery stock from Europe, has been in this country for more than a century (Maloy 2001), but it is just now killing most of the whitebark pine (*Pinus albicaulis*) trees in the northern Rocky Mountains from Glacier National Park to Yellowstone and Grand Teton.

Likewise, hemlock woolly adelgid *(Adelges tsugae),* a tiny insect, also illustrates well the case of serious invasions, which are revealed as serious only gradually. Native to Asia, it reached the western United States in the 1920s and the eastern part of the country in the 1950s, but the conventional wisdom was that it attacked only cultivated hemlocks (Van Driesche and Van Driesche 2000). In the 1980s, reports surfaced of eastern hemlock death in Virginia, and the infestation has now become a huge problem from New England to North Carolina and is slowly spreading westward (see article and illustrations, pages 53–56). This may be an invasion that could cause functional extinction of two hemlock species, eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*Tsuga caroliniana*).

Lag times are not always as long. Balsam woolly adelgid *(Adelges piceae)* has virtually eliminated Fraser fir (*Abies fraseri*) in Great Smoky Mountains National Park; it was first noted in the United States about 1950 and started attacking fir in the Smokies in the 1970s (see article and illustrations, pages 64–65). Dogwood anthracnose *(Discula destructive),* first detected in the country in the 1970s, was reducing or eliminating flowering dogwood (*Cornus florida*) in many eastern national park areas by the 1990s (Langdon and Johnston 1992).

Fast-moving and newly emergent invasive diseases deservedly get the most attention. Sudden oak death syndrome (caused by the fungus *Phytophthora ramorum*) is a high-visibility problem that popped up in 1995 in California and kills healthy trees within four months (Kliejunas 2001). For nearly a decade, the fungus in the United States had been confined to Pacific states, but its chances of invading southeastern states, where numerous potentially susceptible oak *(Quercus)* species are ecological dominants, was learned to have been hastened in early 2004. At that time it was found that in spite of the best preventative efforts of APHIS, one large, infected nursery in Los Angeles had shipped susceptible plant material widely. An APHIS update reported, "As of June 15, *P. ramorum* has been confirmed in plants traced forward from the initially positive Los Angles County wholesaler at 118 sites in 16 states," including 11 states in the southeast (APHIS 2004).

How many more sleeper invasions have already been inoculated within ecosystems worldwide by the recent burgeoning of trade—involving diverse pathways from solid-wood packing and raw lumber to seed trade on the Internet? And how much are protective systems going to improve in the coming decades in addressing continuing inoculations? In my view, change is going to depend more than anything on awareness.

WHO WILL TELL THE PEOPLE?

Entomologists Nemiela and Mattson, in a 1996 article in *BioScience*, stated (p. 751): "When the outrageous economic and ecological costs of the wanton spread of existing exotics and continued entry of new ones become common knowledge, it is inevitable that there will be a public outcry for actions to mitigate the potentially dire consequences." Whose responsibility is it to inform the public?

One might conclude that the seriousness of the problem of biological invasions seems to be largely unrecognized in the consciousness of the American public. Among environmental concerns, clean air and clean water perhaps understandably seem to attract the most attention (since their direct effects are readily imagined). The reality is that biological invasions threaten much more than the integrity of natural ecosystems of national parks. They pose immense threats to the U.S. economy, agriculture, and forest resources, and to the public health and quality of life of U.S. citizens. Yet it seems that almost nowhere in American society is this message being conveyed effectively. Admittedly, the press reports with high frequency on specific invading species, but only rarely produces in-depth analyses relevant to the general problem of invasions (e.g., Nash 2004, Choo 2004).

Biological invasions threaten much more than the integrity of natural ecosystems of national parks.

HOW CAN THE NATIONAL PARK SERVICE RISE TO THE CHALLENGE?

The issue of the threat of invasive alien species to natural areas obviously presents huge challenges, but there are many possibilities for working toward "solutions." A recent issue of *BioScience* presents an upbeat mix of ideas on promising approaches by knowledgeable scientists (Dybas 2004). One such scientist's (Daniel Simberloff) presentation was entitled "We can win this war: The dangers of pessimism about introduced species." Another (David Lodge) is quoted as having made the observation that screening species for invasiveness is one of the essentials and that "we have or are developing the tools to do that. The management and policy tools, however, lag way behind." A third scientist (Ann Bartuska) expressed frustration over "how little we have done about dealing with … [the invasive species issue]—given how big it is, how clearly we know the impacts, how widespread it is, and how it touches everyone in one way or another.… We seem to have the political will and the public will to really take on fire [in wildland management] in a big way … but we don't seem to be able to do the same with invasive species." Her suggested solutions included "integrated vector management" and "an effective early detection rapid response system."

The National Park Service has special incentives for ramping up its efforts to address the invasive species issue. National parks and their ecosystems provide an excellent opportunity to bring the invasions message to the U.S. public. Parks have been identified in the past (originally by NPS Director George Hartzog in the early 1970s) as "miners' canaries" for U.S. environmental health and indeed can well serve as such for communication of the invasions message. Some regions and parks are much more susceptible to invasions than others, with some already showing substantial degradation. Parks in Hawaii, California, and Florida are especially affected by invasions. Those parks provide unfortunate but strong lessons to be learned by NPS employees and the general public. Those fortunate regions and parks that have up to now been less susceptible and have largely escaped damage by invasions can learn from their neighbors and anticipate threats posed by future invasions.

The 1916 NPS Organic Act states clearly that the national parks are to be kept "unimpaired for the enjoyment of future generations." The National Park Service now appears to be faced most ominously with massive impairment of the parks' natural resources by biological invasions from outside. One role for the National Park Service might be to accelerate its proactive role in informing its employees and the American public of the insidious nature of biological invasions. Another might be to include serious analyses of the importance of proactive quarantine systems suitable for regions at risk such as the Hawaiian Islands (see Reeser 2002). Major breakthroughs in science, policy, and management will likely be needed to address the complex and important issue of biological invasions if substantial impairment of the parks is to be averted.

LITERATURE CITED

Animal and Plant Health Inspection Service (APHIS). 2000. Federal noxious weed list. Available at http://www.aphis.usda.gov/ppq/permits/fnwsbycat-e.html (accessed 10 July 2004)

APHIS. 2004. Pest detection and management programs—program update: Phytophthora ramorum, June 17, 2004. Available at http://www.aphis.usda.gov/ppq/ispm/sod/updates/update061704.pdf (accessed 10 July 2004).

Baskin, Y. 2002. A plague of rats and rubbervines: the growing threat of species invasions. Island Press, Washington, D.C.

Bright, C. 1999. Invasive species: pathogens of globalization. Foreign Policy, Fall 1999:50–64.

Campbell, F. C. 2001. The science of risk assessment for phytosanitary regulation and the impact of changing trade regulations. BioScience 51(2):148–153.

Campbell, F. C., and S. E. Schlarbaum. 2002. Fading Forests II: Trading away North America's natural heritage. Healing Stones Foundation in cooperation with the American Lands Alliance and the University of Tennessee, Knoxville.

Coordinating Group on Alien Pest Species (CGAPS). 1996. The silent invasion. Developed collaboratively with CGAPS by InfoGrafik, Inc., Honolulu, HI. Available in part at http://www.hear.org/intro/contents.htm (accessed 30 July 2004).

Choo, D. K. 2004. Unwanted dead or alive: how invasive species could kill our economy. Hawaii Business, April 2004. Available at http://www.hawaiibusiness.cc/hb42004/default.cfm?articleid=1 (accessed 28 August 2004).

Dybas, C. L. 2004. Invasive species: the search for solutions. BioScience 54(7):615–621.

Eldredge, L. G., and N. L. Evenhuis. 2003. Hawaii's biodiversity: a detailed assessment of the numbers of species in the Hawaiian Islands. Bishop Museum Occasional Papers 76:1–28. Available at http://hbs.bishopmuseum.org/pdf/op76.pdf (accessed 17 July 2004).

Food and Agriculture Organization (FAO). 2002. International standards for phytosanitary measures: Publication No. 15. Guidelines for regulating wood packaging material in international trade. United Nations FAO, Secreratiat of the International Plant Protection Convention (IPPC), Rome. Available at http://www.ippc.int/IPP/En/ispm.jsp (accessed 28 August 2004).

FAO. 2004. IPPC and international trade. United Nations FAO. Rome. Available at http://www.ippc.int/id/13422 (accessed 28 August 2004).

Hawaii Department of Agriculture (HDOA). 2002. Kahului Airport pest risk assessment. Department of Agriculture, State of Hawaii, Plant Quarantine Division. Available at http://www.hawaiiag.org/PQ/KARA%20Report%20Final.pdf (accessed 10 July 2004).

Hiebert, R., and others. 2002. Invasive plant inventory and monitoring guidelines. Available at http://science.nature.nps.gov/im/monitor/Meetings/FtCollins_02/InvasivePlantsWorkshop.htm (accessed 10 July 2004).

Invasive Species Specialist Group (ISSG). 100 of the world's worst invasive species: a selection from the Global Invasive Species Database. IUCN, The World Conservation Union, ISSG. Available at http://www.iucn.org/biodiversityday/100booklet.pdf (accessed 10 July 2004).

Kliejunas, J. 2001. Phytophthora ramorum. Available at http://spfnic.fs.fed.us/exfor/data/pestreports.cfm?pestidval=62&langdisplay=english (accessed 10 July 2004).

Langdon, K. R., and K. D. Johnston. 1992. Alien forest insects and diseases in eastern USNPS units: impacts and interventions. The George Wright Forum 9(1):2–14.

Lodge, D. M. 1993. Biological invasions: lessons for ecology. Trends in Ecology and Evolution 8:133–137.

Loope, L. L. 1998. Hawaii and Pacific islands. Pages 747–774 in M. J. Mac, P. A. Opler, C. E. Puckett Haecker, and P. D. Doran, editors. Status and trends of the nation's biological resources. Volume 2. U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia. Available at http://biology.usgs.gov/s+t/SNT/noframe/pi179.htm (accessed 17 July 2004).

Loope, L. L. 2004. New Zealand's border protection quarantine and surveillance: a potential model for Hawai'i. Ecological Restoration 22(1):69–70.

Loope, L. L., and F. G. Howarth. 2003. Globalization and pest invasion: Where will we be in five years? Pages 34–39 in R. G. Van Driesche, editor. Proceedings of the international symposium on biological control of arthropods, Honolulu, Hawaii, 14–18 January 2002. FHTET-2003-05. U.S. Department of Agriculture, Forest Service, Morgantown, West Virginia. Available at http://www.bugwood.org/arthropod/day1/loope.pdf (accessed 17 July 2004).

Loope, L. L., and D. Mueller-Dombois. 1989. Characteristics of invaded islands. Pages 257–280 in J. A. Drake and others, editors. Ecology of biological invasions: a global synthesis. John Wiley & Sons, Chichester, U.K.

Loope, L. L., and D. W. Reeser. 2001. Crossing boundaries at Haleakala: addressing invasive species through partnerships. Pages 29–34 in D. Harmon, editor. Crossing boundaries in park management: proceedings of the 11th conference on research and resource management in parks and on public lands, Denver, Colorado, April 2001. George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/06loope.pdf (accessed 28 August 2004).

McGregor, R. C. 1973. The emigrant pests. A report to Dr. Francis Mulhern, administrator, Animal and Plant Health Inspection Service. Berkeley, California. (Unpublished report on file at Hawaii Department of Agriculture, Honolulu, Hawaii.) Available at http://www.hear.org/articles/pdfs/mcgregor1973.pdf (accessed 28 August 2004).

Maloy, O. C. 2001. White pine blister rust. Plant Health Progress. Available at http://www.plantmanagementnetwork.org/pub/php/management/whitepine/ (accessed 10 July 2004).

Meyer, J. Y. 1996. Status of Miconia calvescens (Melastonataceae), a dominant invasive tree in the Society Islands (French Polynesia). Pacific Science 50:66–76.

Meyer, J. Y., and J. Florence. 1996. Tahiti's native flora endangered by the invasion of Miconia calvescens DC. (Melastomataceae). Journal of Biogeography 23:775–781.

Mooney, H. A., and R. J. Hobbs. 2000. Invasive species in a changing world. Island Press, Washington, D.C.

Nash, S. 2004. Invasion of the buggy snackers (and other horrors). Washington Post, Sunday, 11 April 2004:B2.

Nemiela, P., and W. J. Mattson. 1996. Invasion of North American forests by European phytophagous insects. BioScience 46(11):741–756.

North American Forest Commission. 2000. Alien species harmful to North American forests. Background paper for 20th session, St. Andrews, New Brunswick, Canada, 12–16 June 2000. Available at http://www.fao.org/docrep/meeting/x7000e.htm (accessed 1 September 2004).

OTA (Office of Technology Assessment, U.S. Congress). 1993. Harmful-nonindigenous species in the United States. OTA-F-565. U.S. Government Printing Office, Washington, D.C.

Pheloung, P. C., P. A. Williams, and S. R. Halloy. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57:239–251.

Randall, R. P. 2002. A global compendium of weeds. R. G. and F. J. Richardson. Melbourne, Australia.

Reeser, D. W. 2001. Crossing boundaries at Haleakala: the struggle to get improved quarantine protection prior to expansion of Maui's airport. Pages 107–111 in D. Harmon, editor. Crossing boundaries in park management: proceedings of the 11th conference on research and resource management in parks and on public lands, Denver, Colorado, April 2001. George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/19reeser.pdf (accessed 10 July 2004).

Stone, C. P., and L. L. Loope. 1996. Alien species in Hawaiian national parks. Pages 133–158 in W. L. Halvorson and G. E. Davis, editors. Science and ecosystem management in the national parks. The University of Arizona Press, Tucson.

Tkacz, B. M., H. H. Burdsall, G. A. DeNitto, A. Eglitis, J. B. Hanson, J. T. Kliejunas, W. Wallner, J. G. O'Brien, and E. L. Smith. 1998. Pest risk assessment of the importation into the United States of unprocessed Pinus and Abies logs from Mexico. General Technical Report FPL-GTR-104. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Tunison, J. T., and C. P. Stone. 1992. Special ecological areas: an approach to alien plant control in Hawaii Volcanoes National Park. Pages 781–798 in C. P. Stone, C. W. Smith, and J. T. Tunison, editors. Alien plant invasions in native ecosystems of Hawai'i: management and research. Cooperative National Park Resources Studies Unit, Honolulu.

Van Driesche, J., and R. Van Driesche. 2000. Nature out of place: biological invasions in the global age. Island Press, Washington, DC.

Vermeij, G. J. 1991. Anatomy of an invasion: the trans-Arctic interchange. Paleobiology 17:281–307.

Vitousek, P. M., C. M. D'Antonio, L. L. Loope, M. Rejmanek, and R. Westbrooks. 1997. Introduced species: a significant component of human-caused global change. New Zealand Journal of Ecology 21:1–16.

Werksman, J. 2004. Invasive alien species and the multilateral trading system. Chapter 8. Pages 203–217 in M. L. Miller and R. N. Fabian, editors. Harmful invasive species: legal responses. Environmental Law Institute, Washington, D.C.

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48(8):607–616.

Williamson, M. 1981. Island populations. Oxford University Press, Oxford, UK.

ABOUT THE AUTHOR

Lloyd Loope is station leader of the Haleakala Field Station, USGS, Pacific Island Ecosystems Research Center, P.O. Box 369, Makawao, Maui, Hawaii 96768 (lloyd_loope@usgs.gov).

A RETROSPECTIVE on NPS invasive species policy and management

By Linda Drees

Following habitat loss, exotic species proliferation is considered the greatest threat to our natural heritage. Invasive species encroachment is implicated in the listing of 42% of all species protected by the Endangered Species Act (Stein and Flack 1996). Invasive species cost the U.S. economy $138 billion annually (Pimental et al. 1999). Of the 83 million acres (34 million ha) managed by the National Park Service, 2.6 million acres (1.1 million ha) are infested by exotic plants and nonnative animals. Examples of nonnative animal species plaguing the parks are feral pigs and goats, hemlock woolly adelgid, New Zealand mudsnail, African oryx, and more recently mosquitoes carrying an exotic microbe, West Nile virus. To address the damage of invasive species, a National Invasive Species Management Plan was developed in 200l and is being carried out by federal agencies. The National Park Service, with its long history of fighting harmful invasives, welcomes this interagency coordination in taking on the tremendous challenge of controlling and eradicating invasive species.

Figure 1. Burro removal from Grand Canyon National Park, Arizona, began in 1982 and was initially achieved by trapping (right), relocation to holding pens, and adoption by projects partners, such as the Fund for Animals. Today, those few burros that evaded the earlier trapping efforts (and their offspring) (top) are removed by lethal methods, as specified in the environmental impact statement for the park burro management plan. Despite these efforts, some reclusive burros still persist in the park today. NPS PHOTOS

The National Park Service has been a pioneer in combating threats to resources posed by invasive species. This work began with the grassroots efforts of park staff removing feral pigs at Great Smoky Mountains National Park, burros at Grand Canyon National Park (fig. 1), and purple loosestrife at Acadia National Park. As more and more invasives have encroached on parklands over the last century, the National Park Service has committed more resources, developed more complex programs and policies, and strengthened its resolve to deal with and manage invasives.

Historical warnings: the crucible of policy

The Organic Act of 1916 is the origin of NPS policy on exotic species. The National Park Service was created to preserve examples of the natural and historic objects characteristic of the United States. With respect to living things in the National Park System, the term "natural objects" has come to mean individual plants and animals, their species and habitats, and their ecological systems. This definition instructs the National Park Service to protect (or in many cases manage *toward*) (1) resource conditions that were present before a major increase in the rate of human impacts, and (2) resource conditions that would still exist today had modern people not interfered with the normal processes of ecological and evolutionary change.

In managing natural resources and historic objects, the National Park Service recognized that some park species were "exotic." As the National Park Service gained experience with management of parks and their living objects, its definition of exotic species became clearer, reflecting the complex relationships among organisms in the landscape. The basis for this evolution has been the National Park Service's relatively early recognition that exotic species threaten the preservation of park natural resources. For example, in 1932 the NPS field biologists George Wright, Joseph Dixon, and Ben Thompson authored a report called the *Fauna of the National Parks of the United States* that identifies the threat of exotic species. The following excerpt from the report qualifies as one of the first warnings to park managers on the implications of exotic species.

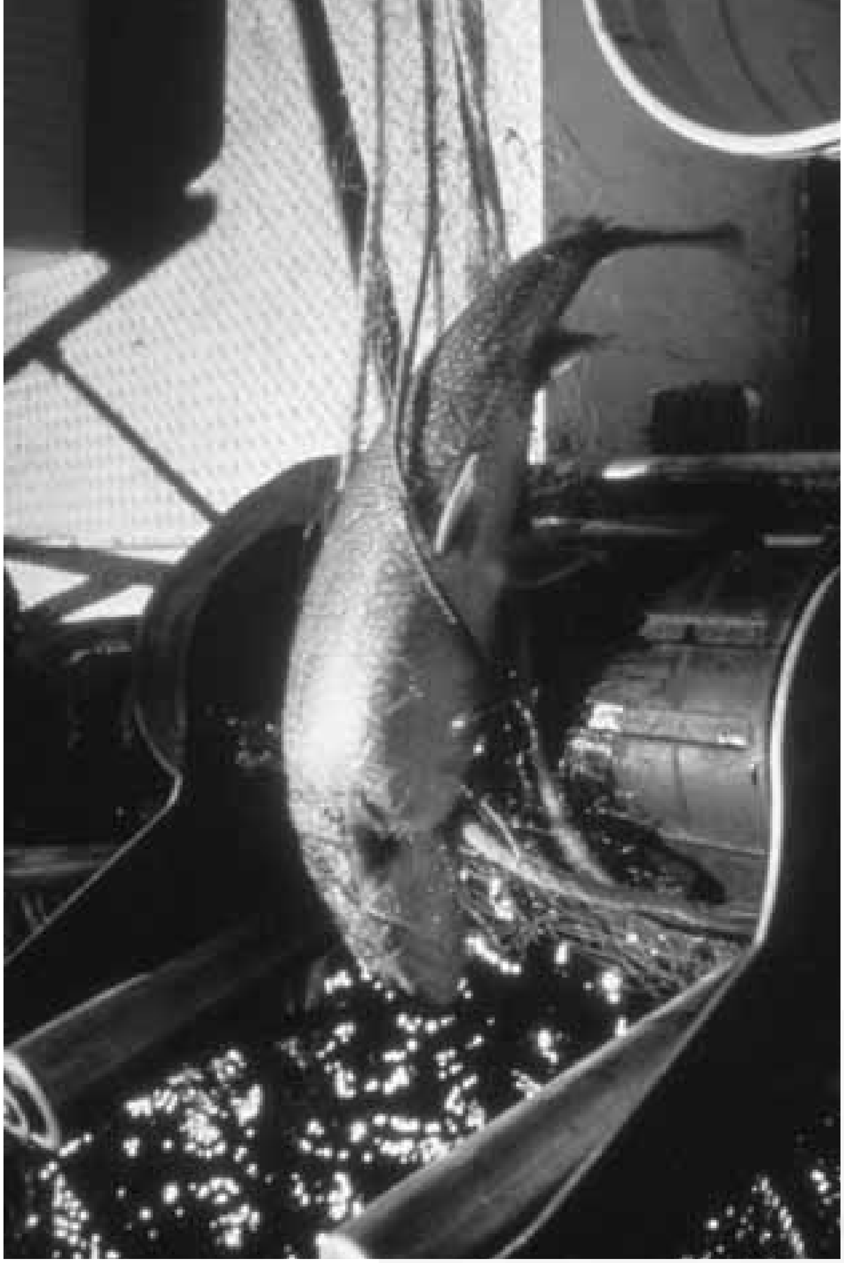
As the National Park Service gained experience with management of parks and their living objects, its definition of exotic species became clearer, reflecting the complex relationships among organisms in the landscape.

> [Encroachment of exotic species upon the natural park fauna] is a situation which is not apparent in many parks at present, *but which is apt to become more and more difficult*. There are three ways in which man has brought about the introduction of exotics.
>
> (1) Many important species of animals, notably game birds and fishes, are liberated all over the country each year in the interests of sportsmen.
>
> (2) Exotic species are constantly being liberated by accident.
>
> (3) Certain animals native to one part of the country actually flourish with civilization and invade new ranges in the wake of man. These are exotic in their newly occupied ranges, too.

Even when Yellowstone—the first national park—was in its infancy, its managers resisted adding new plants and animals because of the damage caused by the introductions.

Two reports of the 1960s—the Leopold report on wildlife management in the national parks (Leopold et al. 1963), and the Robbins report on research (Robbins et al. 1963)—asserted that the introduction of exotic species was inappropriate for areas set aside to preserve natural conditions. Reacting to the Leopold report, Secretary of the Interior Udall issued a memorandum dated 2 May 1966 instructing the director of the National Park Service "to incorporate the philosophy and the basic findings of the report into the administration of the National Park System" (Commission on Geosciences, Environment, and Resources 1992). With respect to exotic species, the Park Service responded informally in statements such as one by the principal NPS biologist Lowell Sumner in 1964 that "nonnative species are to be eradicated, or held to a minimum if complete eradication is impossible." In 1968 the National Park Service answered with formal publication of the Administrative Policies for Natural Areas of the National Park System, which declared that "nonnative species may not be introduced into natural areas. Where they have become established or threaten invasion of a natural area, an appropriate management plan should be developed to control them, where feasible.…" It went on to state that "nonnative species of plants and animals will be eliminated where it is possible to do so by approved methods which will preserve wilderness qualities" (National Park Service 1968).

Similarly, in revising its exotic species policy in 1975, 1988, and 2001, the National Park Service maintained the prohibition of introducing new exotic species into natural zones of parks (although, controlled introductions of exotics into historic, developed, and special use zones of parks was permitted). All three policy documents maintained that control or eradication of existing populations of exotic species would occur in a variety of situations where park purposes or adjacent, privately held lands were being threatened by such species.



Parks take action

Over the last century parks throughout the country have taken creative and concrete steps toward controlling harmful invasive species. Yellowstone National Park has removed thousands of nonnative lake trout since 2000 because they were displacing native fish (fig. 2). African oryx were intentionally introduced into New Mexico the 1960s and grew to a herd numbering more than 4,000. However, oryx were physically damaging White Sands National Monument and control was necessary (see article, page 6). The park initiated a comprehensive control program in 1999 and successfully removed all oryx from the park. At St. Croix National Scenic Riverway (Wisconsin and Minnesota), a boat inspection program has been initiated with the State of Minnesota and federal agencies to prevent the spread of invasive aquatic plants and zebra mussels into the unit. This prevention program was initiated to stop the introduction of zebra mussels, which were outcompeting threatened and endangered native mussels (see article, pages 66–67).

Finally, invasive plant control has been carried out in almost every natural resource park in the National Park System. Even with the Herculean efforts by parks to reduce invasive species, it became increasingly clear an

Figure 2. (Right) Fisheries crew member John Bauer secures a gill net after its deployment in Yellowstone Lake for the removal of nonnative lake trout (top). The ongoing control program at Yellowstone National Park is necessary to protect native cutthroat trout from this invasive competitor. NPS PHOTOS

NPS policy and funding strategy were needed. The National Park Service responded by dedicating one of its overarching natural resource management goals to measure its performance relative to the containment of exotic plants (Government Performance and Results Act [GPRA] 1a1b). Since 1999, the National Park Service has controlled exotic plant species on more than 167,000 acres (67,635 ha); however, 2.6 million acres (1.1 million ha) remain infested. The National Park Service has met or exceeded performance levels for GPRA goal 1a1b each year since this goal's inception in 2000.

Finding institutional solutions

The Washington Office of the National Park Service first responded to problems posed by exotic species with the creation of the Integrated Pest Management (IPM) program in the 1980s. This program was developed because of concerns related to documented increases in the use of chemicals to control native and nonnative pests, such as termites and cockroaches, on park lands. The National Park Service received a grant for $80,000 from the Environmental Protection Agency and initiated a pilot IPM program within the National Capital Region. The program has since grown and is now viewed by other natural resource agencies as a model for managing pest species. The IPM program supplies a broad range of technical assistance and training to park staffs on the low-risk management of exotic and native pests that adversely affect park operations, natural and cultural resources, visitor safety, and concessions. These services are given to more than 100 parks per year through on-site or remote consultations by IPM staff, technical manuals, or other means, and the identification of non-NPS experts who can assist. The result is often an economic and permanent solution to pest management problems in parks.

The next significant response to invasive species came in 1996 when the National Park Service published "Preserving our Natural Heritage: a strategic plan for managing invasive nonnative plants in the National Park System." It outlines a framework for a national invasive species program. This plan has earmarked funding from the Natural Resource Preservation Program (NRPP) on invasive species control projects, which numbered 46 in 2002 and totaled more than $1.6 million. Despite this financial boost, an assessment conducted in the 1990s of staffing and funding needs for a viable invasive species program was estimated at $80 million per year for the National Park Service.

The unrelenting demand for exotic species management and research resulted in a full-scale needs assessment under the Natural Resource Challenge initiative. First funded in 2000, the Challenge comprises several action plans related to natural resource management.

Figure 3. Crew members of 13 of the 15 NPS EPMTs, along with university staff and representatives of Mexico's national parks, traveled to Arches National Park, Utah, in 2004 to control 25 acres (10 ha) of tamarisk in Courthouse Wash. The operation, which was funded in conjunction with the NPS Fire Program, exceeded its goal by 100%, controlling 50 acres (20 ha) of the invasive tree species. The operation was the first to bring together several EPMTs for a joint training and work exercise, and resulted in no injuries to participants. NPS PHOTOS

The exotic species action plan is the most recent, ambitious, and comprehensive approach to invasive species management in the National Park Service. It identified the need to form the Biological Resource Management Division (BRMD) under the umbrella of the Natural Resource Program Center. The division develops policy and technical assistance programs, and awards NRPP funding to help parks manage native and nonnative species. The Invasive Species Branch of BRMD operates the IPM program and Exotic Plant Management Teams (EPMTs). These mobile, specialized EPMTs are the first to be established among federal land management agencies. Thanks to Natural Resource Challenge funding, the National Park Service now has 16 EPMTs that assist 209 national parks. Since the inception of the program in 2000, the EPMTs have treated more than 73,000 acres (29,565 ha) (fig.3). As partnerships are expanded and the expertise of the teams becomes institutionalized, the National Park Service anticipates the future benefit of this program to grow exponentially.

Needs beyond parks

Recognition of the problems associated with invasive species beyond national park boundaries is growing. In the last decade, both the National and Western Governors Associations have adopted policy on invasive species and specifically called for federal action and coordination. In 1999, President Clinton responded to the governors' resolutions by signing Executive Order 13112 on invasive species. The executive order established an invasive species council made up of eight departments of the federal government. The partnership established under the executive order will promote a concerted and coordinated management of invasive species across the country.

For the future

The National Park Service has steadily progressed through the development of innovative programs to manage invasive species. Its policies are solid, committing the National Park Service to protect park resources from invasive species. Yet most on-the-ground management is carried out as collateral duties of existing resource management staff rather than by trained invasive species specialists. However, the National Park Service cannot expect additional internal funding to solve its problems. Rather, it must look to creative mechanisms to leverage funds and expertise through partnerships. For example, the State of Florida makes dollar-for-dollar matching grants for control of exotics. In 2003, EPMTs received $2.8 million in outside contributions to conduct invasive weed work in national parks.

Most on-the-ground management is carried out as collateral duties of existing resource management staff rather than by trained invasive species specialists.

In addition to leveraging more resources for the control of invasives, the National Park Service must integrate restoration more thoroughly into its efforts. In some cases disturbances from park-based management activities have led to the ease with which invasives have become established. Restoration of ecosystems can reduce the encroachment of invasive species and is the next challenge for the National Park Service in protecting this country's natural heritage for future generations.

In 2003, EPMTs received $2.8 million in outside contributions to conduct invasive weed work in national parks.

Increasingly obvious as the best strategy for battling invasive plants is preventing them from entering our national parks. New and innovative programs are being established in a handful of parks to institutionalize prevention programs. In cases where this is not possible, the sooner new introductions are detected and addressed the greater the likelihood of eradication. Fortunately, the NPS Inventory and Monitoring (I&M) Program has identified the spread of invasive species as a premier threat to ecosystem function. Many I&M networks are helping parks develop monitoring programs for the detection of new invasions, so a quick response can ultimately remove the threat *before* it becomes unmanageable.

Restoration of ecosystems can reduce the encroachment of invasive species and is the next challenge for the National Park Service in protecting this country's natural heritage for future generations.

This is a golden time for managing invasive species in national parks. Recognition that invasives are a major threat to our natural heritage is broad-based, and includes such groups as our partners, constituents, park visitors, and the Bush administration. New policies and increased funding through the Natural Resource Challenge reflect a commitment to take action to manage invasive species. If we stay the course, management of invasive species in parks is within our grasp.

Literature cited

Commission on Geosciences, Environment, and Resources. 1992. Science and the National Parks. National Research Council, National Academy Press, Washington, D.C.

Leopold, A. S., S. A. Cain, C. M. Cottam, I. N. Gabrielson, and T. L. Kimball. 1963. Wildlife management in the national parks: advisory board on wildlife management appointed by Secretary of the Interior. Transactions of the North American Wildlife and Natural Resources Conference 28:29–44.

National Park Service. 1968. Administrative Policies for Natural Areas of the National Park System. U.S. Government Printing Office 16–21. Washington, D.C.

Pimental, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50(1):53–65.

Robbins, W. J., E. A. Ackerman, M. Bates, S. A. Cain, F. D. Darling, J. M. Fogg Jr., T. Gill, J. M. Gillson, E. R. Hall, C. L. Hubbs, and C. J. S. Durham. 1963. A Report by the Advisory Committee to the National Park Service on Research. National Academy of Sciences, National Research Council, Washington, D.C.

Stein, B. A., and R. S. Flack, editors. 1996. America's least wanted: alien species invasions of U.S. ecosystems. The Nature Conservancy, Arlington, Virginia.

Wright, G. M, J. S. Dixon, and B. H. Thompson. 1933. Fauna of the national parks of the United States: a preliminary survey of faunal relations in national parks. Fauna series 1. U.S. Government Printing Office, Washington, D.C.

About the author

Linda Drees is chief of the Exotic Species and Restoration Branch of the NPS Biological Resource Management Division in Fort Collins, Colorado. She is also the coordinator of the Exotic Plant Management Teams, and can be reached at 970-225-3595 or linda_drees@nps.gov.

Assessing the invasive plant issue

By Pamela Benjamin and Ron Hiebert

As a major focus of the Natural Resource Challenge, management of alien species has begun to receive an increasing amount of support throughout the National Park Service (NPS). In particular, the establishment of Exotic Plant Management Teams (EPMTs) is a major contribution to increasing our ability to control invasive weeds. However, an array of assessment tools is needed in order to ensure that these teams, as well as monitoring network and park staffs, target the control of invasive plants of highest priority, in areas of greatest value, and with the highest potential for restoration.

Several approaches have begun to provide consistency in the inventory and mapping of weeds (Beard et al. 2001, Benjamin 2001), to establish guidelines for long-term monitoring (Hiebert 2002), and to assist in the assessment of the restoration potential of weed-infested sites (Benjamin 2004). Yet, despite these substantial advances, limitations remain that significantly jeopardize our attempt to win the battle against invasive plants.

This article focuses on the role of weed assessments in developing effective weed management strategies at multiple levels throughout the National Park Service. It also summarizes the benefits of emerging guidelines for the inventory, mapping, and monitoring of invasive weed species, and for assessing the restoration potential of weed-infested areas. Furthermore, it provides specific recommendations on future steps needed to ensure that the National Park Service continues to serve its role in preserving the natural and cultural heritage of this nation.

Importance of establishing a baseline

Most parks lack complete weed inventories, which makes assessing impacts and establishing management priorities difficult. By far, the overriding benefit of evaluating weed infestations in parks is the resulting ability of resource managers to analyze and prioritize invasive plant management needs, and to appropriately direct work efforts and resources. As such, understanding baseline conditions can enhance the time and cost-effectiveness of invasive plant management actions. Additionally, documenting areas not yet infested is as important as documenting the locations of where weeds occur. This information affords resource managers the greatest opportunity to be proactive and to employ the most cost-effective and efficient of all weed management strategies—prevention.

Documenting areas not yet infested is as important as documenting the locations of where weeds occur.

Assessing invasive plant issues is not a simple undertaking and requires the integration and understanding of complex physical, biological, and ecological factors. Resource managers need to address several basic, but often difficult-to-answer, questions before effective weed management strategies can be identified and implemented. These questions can be categorized and include:

Assessing invasive plant issues is not a simple undertaking and requires the integration and understanding of complex physical, biological, and ecological factors.

- **Inventory, mapping, and monitoring**
  What is the distribution and relative abundance of weeds within and adjacent to a park? What physical and biological factors are contributing to the distribution? How is the distribution of weeds changing over time?

- **Identifying priority species and priority treatment areas**
  Which species are most invasive or represent the greatest threat to park resources? What is the biology of the targeted weed species? Which areas are currently not infested by alien plants? Which areas have the highest ecological significance or integrity?

- **Identifying the restoration potential of an area**
  What type of disturbance or activity has allowed invasive species to become established? What is the potential for a site to be restored to its natural condition and maintained thereafter? What is the restoration feasibility of a weed-infested site? What types of management actions are needed? What level of expertise is required to ensure recovery of the targeted natural system or landscape?

Guidelines for inventory, mapping, and monitoring

In 2002 the NPS Inventory and Monitoring (I & M) Program hosted a workshop in Fort Collins, Colorado, to develop guidelines and tools that would support I & M networks, parks, and cooperating land managers in developing protocols for inventory and monitoring of invasive plants. The objective of the workshop was to compile, apply, and modify existing inventory, mapping, and monitoring guidelines and protocols, and not to "reinvent the wheel." The document resulting from the workshop is available from the NPS Inventory and Monitoring Web site (Hiebert 2002).

Effective invasive plant management requires identified goals, measurable objectives, and protocols for inventory, mapping, and monitoring (fig. 1). Following this structure, workshop participants proposed and adopted for use four general inventory, mapping, and monitoring goals for mitigating invasive plants throughout the National Park System:

1. Determine the distribution and abundance of known nonnative plant species within and surrounding parks. Assess which plants are present and which have a high potential to become invasive.

2. Prevent and detect new alien plant invasions, and eradicate new invasives.
3. Evaluate the effects of management actions on targeted plant species and the ecosystems they have invaded, and determine whether management actions have accomplished strategic goals.

4. Determine the status and trends of plant invasions over time and space, and develop predictive models to better guide future monitoring and management efforts.

Workshop participants also agreed that specific data elements as identified by the North American Weed Management Association (NAWMA) (Beard et al. 2001)

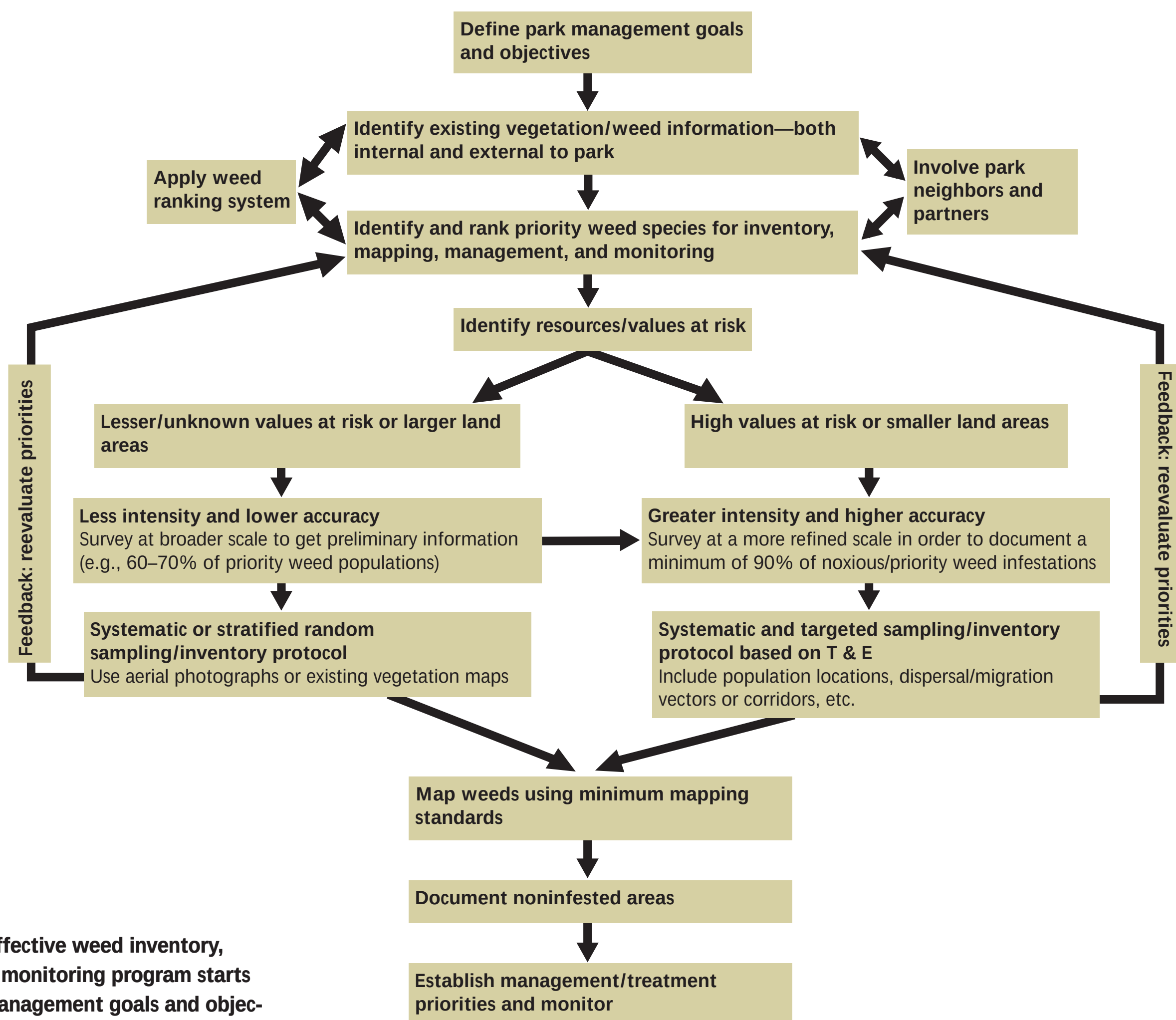


Figure 1. An effective weed inventory, mapping, and monitoring program starts by defining management goals and objectives. FROM BENJAMIN (2001)

and by the draft Intermountain Region "Weed Inventory, Mapping, and Database Development Guidelines" (Benjamin 2001) should be adopted as the NPS standards for invasive plant inventory and mapping. Currently, all state and federal land managing agencies in the western United States have adopted the NAWMA standards. Wide use of these basic data standards in the collection of weed distribution information provides the greatest ability to share meaningful information between agencies while assessing weed distributions and impacts at multiple scales (park, network, and region). A listing of the NPS-adopted standards and data elements (required and optional) and their definitions appear in Appendix A of the workshop report (Hiebert 2002).

Identifying priority species and priority areas for treatment

Mapping, controlling, and monitoring all nonnative plants in all units of the National Park Systems is physically and fiscally impossible. Although a majority of nonnative plants are relatively innocuous and do not tend to invade intact habitats or cause significant negative impacts in or near parks, the presence of invasive nonnative weeds requires focused management efforts. Therefore, managers must be able to prioritize species and the locations for management for species identified as being invasive (or capable of causing adverse impacts). To assist in these efforts, the Alien Plants Ranking System (APRS)—a cooperative effort among the National Park Service, Northern Arizona University, Ripon College, University of Minnesota, and the U.S. Geological Survey—helps managers prioritize decisions concerning invasive nonnative plants. This automated system ranks species based upon their current presumed site impacts, their innate ability to be pests, and the feasibility of control (ARPS Implementation Team 2001).

The Alien Plant Ranking System has proven to be an extremely beneficial tool in prioritizing invasive species at park and local levels. However, a preliminary screening before species are ranked at a specific site is often necessary. Morse and others (2004) developed criteria that prioritize invasive plants on national or regional scales and rank species based on their negative impacts to native biodiversity. Currently available on the Web, this new ranking tool places invasive species in one of four categories: high, moderate, low, or insignificant based on their potential for adverse impact on a landscape scale (see Morse et al. 2004 for address). This system is beginning to receive wide acceptance and has been adopted by several states to rank invasive weed species, including Virginia, California, Arizona, and Nevada. We propose that this system could be used to categorize priority species at the I & M network level and for identifying the highest priority invasive species regionally. Priority species ranked in the high and moderate categories at the regional or network level could then be further prioritized at the park level using the Alien Plant Ranking System.

A conceptual framework for assessing invasive plants at the I & M network level begins by categorizing nonnative plants known to exist within the geographical area of a network (fig. 2). Species that are thus categorized as causing high, or possibly moderate, impacts to regional biodiversity would be targeted as priorities for surveys and mapping in parks. Parks and areas of parks where a priority invasive species does not occur would also be documented during this process. Park and network managers would then target areas identified as not infested for prevention and early detection efforts. Based upon survey data and additional ranking through the Alien Plant Ranking System, managers would tally a list of priority species for each park within the network. A system similar to the New Zealand site-led system (Timmons and Owens 2001) could then be applied to rank the relative ecological value of invaded and non-invaded sites within

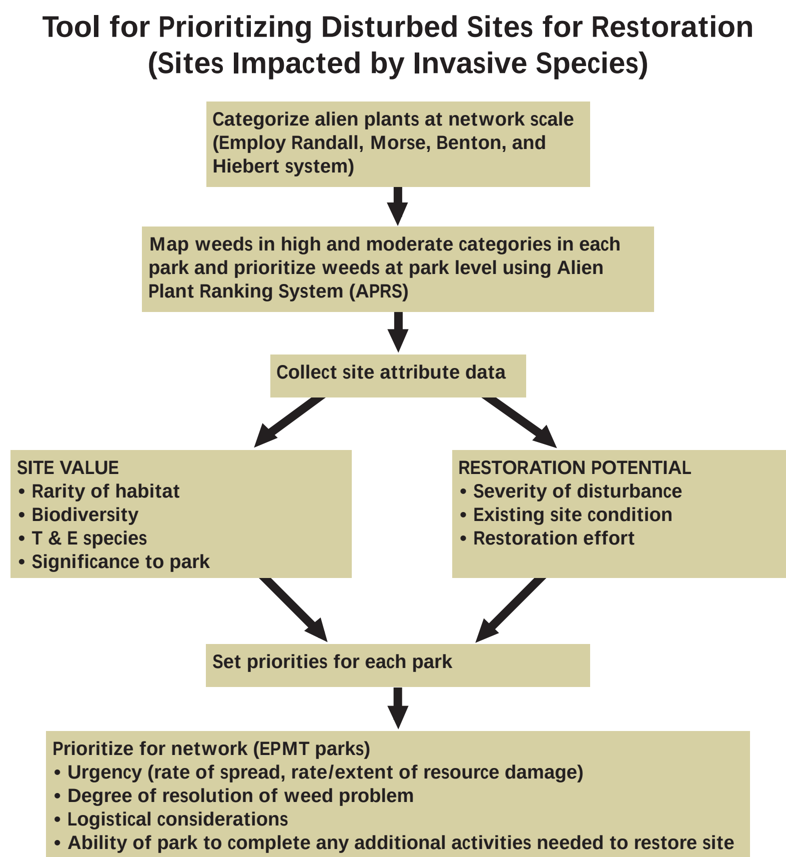


Figure 2. Prioritizing weed management sites begins by categorizing alien plants known to exist within the geographical area of an I & M network.

parks. Concurrently, invaded sites would be evaluated based upon the feasibility and level of effort required to restore the site. Using general inventory, mapping, and monitoring goals, managers would determine priority species and sites for management action for each park within the network. This information would then serve as the basis for prioritizing management actions and monitoring by EPMTs or by individual park staffs.

Assessing the restoration potential of weed-infested sites

A specific goal of all invasive plant management actions is not just to eliminate alien plants but also to protect or restore the function, structure, and composition of the ecosystems that the National Park Service is entrusted to manage. Because the presence of weed species is as much a symptom of degraded habitat as it is a cause, land managers must begin to holistically evaluate weed-infested lands by addressing the question: What is happening in the system that allowed the weeds to invade and become established?

What is happening in the system that allowed the weeds to invade and become established?

As part of an overall effort by the NPS Geologic Resources Division and NPS Biological Resource Management Division to develop a disturbed lands "restoration assessment tool," staffs have initiated work that will build upon inventory, mapping, and identified management priorities by assisting land managers in assessing the restoration potential of weed-infested sites. The restoration assessment tool (Benjamin 2004) builds upon an easy-to-use format (similar to that used by the Bureau of Land Management for assessing "potential natural communities and rangeland health" [Pellant et al. 2000]), and provides both direct and indirect assessments of several parameters related to the ecological integrity of a site. The NPS Washington Office has received funding to field-test this tool, with preliminary testing beginning in 2004. The data collected from these preliminary field investigations will be subsequently used to identify any modifications needed to ensure the greatest application of the restoration assessment tool throughout the National Park System. We expect a formal version of the restoration assessment tool to be available for implementation by the end of 2006.

Future steps

Examples of progress and success in NPS efforts to address invasive plant threats include exemplary programs at Acadia, Glacier, Rocky Mountain, and Yellowstone National Parks, and parks in southern Florida, Hawaii, and the National Capitol Region. The creation of 16 Exotic Plant Management Teams and the increase in park base funding provided by the Natural Resource Challenge also indicate progress. In addition, assessing invasive plant issues and designing weed monitoring programs are high priorities for many I & M networks. Yet, the fiscal and human resources needed for larger-scale inventory and mapping of weed infestations, for the development and implementation of long-term weed management strategies and associated monitoring, and for assessing the restoration potential of weed-infested sites remain low. Without augmented resources and a more coordinated effort, we predict the impacts of invasive plants will continue to increase. To counter this continued spread of invasive plants, some necessary, immediate actions are required.

- Develop stronger policy to support effective prevention and proactive management actions throughout the National Park Service.
- Establish designated invasive plant management positions for parks and monitoring networks. This issue is much too large and serious to address as a collateral duty.
- Establish regional invasive species coordinator positions to (1) enhance invasive species management and partnership abilities (e.g., inventory and mapping; species assessments, control, restoration, and research; and needed regional partnerships), (2) coordinate performance management goals related to invasive species, (3) maintain regional database(s) related to invasive species management (e.g., infested areas, pesticide use), (4) facilitate the development and implementation of regional and network invasive species action plans, (5) coordinate performance management goals related to invasive species, and (6) serve as NPS regional liaisons for regional and national initiatives or working groups related to invasive species management.
- Enhance research capabilities and funding for invasive species research.

Conclusion

Invasive plants represent one of the greatest threats to the natural and cultural resources in the National Park System, yet until recently, our abilities to address this threat have been limited. The creation of EMPTs has proven invaluable in our abilities to undertake invasive plant control activities. However, the development of baseline information and viable tools for assessing and prioritizing weed management and restoration activities is critical to ensure the best use of limited personnel and financial resources. As such, new tools and conceptual frameworks are being developed to improve weed management and habitat restoration capabilities. These contributions represent a significant step forward in addressing the invasive plant issue, yet without further augmentation of resources (personnel and funds), invasive weeds will remain a prominent threat to the resources of our national parks.

References

APRS Implementation Team. 2001. Alien Plants Ranking System, version 7.1. Southwest Exotic Plant Information Clearinghouse, Flagstaff, Arizona. Available at http://www.usgs.nau.edu/swepic/ (accessed 6 July 2004).

Beard, R., C. Searle, D. Bruno, J. Rife, D. Cline, and B. Mullen. 2001. Weed mapping standards. North American Weed Management Association, Granby, Colorado. Available at http://www.nawma.org (accessed 6 July 2004).

Benjamin, P. K. 2001. Weed mapping and database development guidelines. National Park Service, Intermountain Regional Office, Denver, Colorado: draft manuscript.

Benjamin, P. K. 2004. A preliminary report on the development of a disturbed lands restoration assessment tool: a draft concept. National Park Service, Intermountain Regional Office, Denver, Colorado.

Hiebert, R., editor. 2002. Guidelines for inventory and monitoring of invasive plants: report of the workshop on invasive plant inventory and monitoring protocols. National Park Service, Ft. Collins, Colorado. Available at http://science.nature.nps.gov/im/monitor/docs/inv_InvasivePlantsGuidelines.doc (accessed 6 July 2004).

Pellant, M., P. Shaver, D. A. Pyke, and J. E. Herrick. 2000. Interpreting indicators of rangeland health, version 3. Technical reference 1734-6. Bureau of Land Management, National Science and Technology Group, Denver, Colorado.

Morse, L. E., J. M. Randall, N. Benton, R. Hiebert, and S. Lu. 2004. An invasive species assessment protocol: evaluating nonnative plants for their impact on biodiversity, version 1. NatureServe, Arlington, Virginia. Available at http://www.natureserve.org/library/invasiveSpeciesAssessmentProtocol.pdf (accessed 6 July 2004).

Timmons, S. M., and S. J. Owens. 2001. Scary species, superlative sites: assessing weed risk in New Zealand's protected natural areas. Pages 217–227 in Groves, R. H., F. D. Panetta, and J. G. Virtue, editors. Weed Risk Assessment and CSIRO Publishing, Collingwood, Australia.

About the authors

Pamela Benjamin is the vegetation ecologist for the NPS Intermountain Regional Office in Denver, Colorado. She can be reached at pamela_benjamin@nps.gov or 303-969-2865.

Ron Hiebert serves as the research coordinator for the Colorado Plateau Cooperative Ecosystem Studies Unit at Northern Arizona University in Flagstaff, Arizona. He can be reached at ron.hiebert@nau.edu or 928-523-0877.

"Information Crossfile" continued from page 9

Under natural conditions—without earthworms—fallen leaves decompose slowly, creating a spongy layer of organic duff, which is the natural growing environment for native woodland ferns and wildflowers. The duff layer also provides habitat for ground-dwelling animals and helps prevent erosion (Holdsworth et al. 2004). Invading earthworms eat the leaves that create duff, thereby eliminating the layer and decimating forest floors. Mature trees survive, but saplings, ferns, and flowers perish.

Although beneficial in many urban and agricultural settings, earthworms create a soil of a certain consistency, which can have adverse effects in northern forest ecosystems by actually compacting soil. Compaction decreases water infiltration, and less infiltration combined with less duff results in increased surface runoff and erosion (Holdsworth et al. 2004).

In addition to changing the structure of soil, exotic earthworms alter the chemistry of soil. Invasion alters the location and nature of nutrient cycling in soil profiles and changes total carbon and phosphorus pools, carbon-nitrogen ratios, and the loss and distribution of different phosphorus fractions. The organism factor in soil formation also is affected by earthworm invasion: the distribution and function of roots and microbes is significantly disturbed (Bohlen et al. 2004).

The take-home lesson: Exotic earthworm invasion is a significant factor that will influence the structure and function of temperate forest ecosystems over the next few decades. Researchers have little doubt that earthworms are invading new habitats in northern forest ecosystems and that such invasion constitutes a potentially important change in these systems over wide geographic areas (see pages 61–62). If earthworm invasion is an important factor influencing patterns of nutrient cycling and loss in northern forests in the coming decades, then regional evaluations of forests will need to consider the presence or absence of earthworms along with other important drivers of those processes, such as pollution, climate, or underlying soil characteristics (Bohlen et al. 2004). —K. KellerLynn

References

Bohlen, P. J., P. M. Groffman, T. J. Fahey, M. C. Fisk, E. Suárez, D. M. Pelletier, and R. T. Fahey. 2004. Ecosystem consequences of exotic earthworm invasion of north temperate forests. Ecosystems 7:1–12.

Holdsworth, A., C. Hale, and L. Frelich. 2004. Earthworms: contain those creepy crawlers. University of Minnesota Center of Hardwood Ecology and Minnesota Department of Natural Resources, Saint Paul, Minnesota. Available at http://www.dnr.state.mn.us/invasives/terrestrialanimals/earthworms/index.html (accessed 26 July 2004).

The role of fire and fire management in the invasion of nonnative plants in California

By Kyle E. Merriam, Tom W. McGinnis, and Jon E. Keeley

Invasive nonnative plants threaten natural resources throughout the National Park System. Nonnative plant species infest an estimated 4,600 new acres (1,863 ha) of federal land each day (National Park Service 1996), and National Park Service (NPS) policy directs resource managers to develop strategies to control or eliminate nonnative species. However, eradicating nonnative plants has proven to be difficult. One significant challenge is that fire and fire management strategies may be promoting the invasion of nonnative plants in some ecosystems. This is a serious dilemma for resource managers because fire is an important natural process and critical resource management tool on many NPS-administered lands.

Fire and fire management strategies may be promoting the invasion of nonnative plants in some ecosystems.

In this article we describe research being conducted by the U.S. Geological Survey, Biological Resources Division (USGS-BRD), to address the role of fire and fire management programs in the invasion of nonnative plants. We are studying how nonnative plants respond to fire and fire management strategies, and investigating the factors that influence this response. We hope this information will allow NPS resource and fire managers to develop fire management strategies that maintain the important role of fire within the National Park System, while also reducing the negative impacts of many nonnative plant species.

The link between invasive nonnative species and fire and fire management strategies

Managing invasive nonnative plants has become a priority for the National Park Service. The "Strategic Plan for Managing Invasive Nonnative Plants on National Park System Lands" (NPS 1996) recommends strategies to control nonnative plants, including prevention, public awareness, inventory and monitoring, research, and management. Many of these strategies are currently being implemented through NPS resource management plans, inventory and monitoring programs, fire monitoring programs, species-specific eradication programs, and integrated pest management plans.

One significant challenge to resource managers is that fire, an important natural process and management tool on many NPS-administered lands, may be facilitating the invasion of nonnative plant species in some areas. Studies in a number of ecosystems have found that fire often promotes nonnative plants (see D'Antonio 2000 for a review). Fire, like many disturbances, can provide openings for nonnative plant establishment, reduce competition with native species, and create favorable environmental conditions for nonnative plant species, such as elevated nutrient levels. In many cases, nonnative plant species are well adapted to fire, and can invade fire-adapted ecosystems, particularly when natural fire regimes have been altered (Keeley 2001). Once established, nonnative plants can alter fire regimes in their new habitats. They can affect the frequency and intensity of fires by altering fuel characteristics and microclimatic variables such as humidity and wind speed. For example, invasive nonnative grasses have increased fire intensity and frequency in a number of ecosystems throughout the world by increasing the amount of continuous fine fuels across formerly patchy landscapes (D'Antonio and Vitousek 1992). In the Great Basin, fire return intervals have decreased from 30 to 100 years to 5 years in some areas (Whisenant 1990). Native woody species in a variety of habitats cannot tolerate intense and frequent fires, and as a result many areas have been transformed from diverse native woodlands and shrublands into homogeneous exotic grasslands.

Once established, nonnative plants can alter fire regimes in their new habitats.

Prescribed burning has been suggested as a means to control both perennial and annual nonnative plants in some areas. However, the frequency, intensity, and timing of the prescribed burn must be carefully controlled to exploit a vulnerable life history stage of the target species. For example, burning prior to seed release can temporarily reduce the abundance of nonnative annuals. However, this approach may also negatively affect native annual plants. Prescribed fire may inhibit one nonnative species while promoting another. For example, in one study in the Sierra Nevada foothills of California, prescribed burning was effective at reducing the dominance of nonnative grasses, but increased the dominance of nonnative forbs (Parsons and Stohlgren 1989). Resource managers may have to weigh the benefits of controlling one plant species through prescribed burning against the costs of damaging a native plant species or promoting another nonnative plant species. In areas where nonnative plant species have a well-established seed bank, fire is generally an ineffective means of control.

Resource managers may have to weigh the benefits of controlling one plant species through prescribed burning against the costs of damaging a native plant species or promoting another nonnative plant species.

In areas where nonnative plant species have a well-established seed bank, fire is generally an ineffective means of control.

Many fire management plans include fuel reduction strategies such as thinning and the construction of fuel breaks. The role of fuel breaks in promoting nonnative plants has not been specifically studied. However, fuel breaks share many common characteristics with roads, which have been extensively linked with nonnative plant invasion (D'Antonio et al. 1999). Fuel manipulations create disturbance by removing vegetation, opening forest canopies, disturbing soils, and changing hydrologic conditions, factors that generally promote nonnative plants (D'Antonio et al. 1999). Equipment used to construct fuel breaks or to thin forests may transport the seeds of nonnative plant species into areas where they were not formerly present. The effect of localized fuel treatments on nonnative plant invasions can be profound. The establishment of nonnative plants in fuel breaks may provide an exotic seed source in close proximity to remote wildland areas. These wildland areas are then more susceptible to invasion, particularly following disturbances such as natural or prescribed fires (D'Antonio 2000). Nonnative plant invasion in fuel manipulation zones could also increase fire frequencies and alter fire intensity to the detriment of native plant communities (Keeley 2001).

The establishment of nonnative plants in fuel breaks may provide an exotic seed source in close proximity to remote wildland areas.

Maintaining fire and fire management while decreasing the risk of invasive nonnative plant species

Fire is an important natural process and resource management tool on many NPS-administered lands. Fire management strategies include wildland fire use, prescribed burning, and fire suppression. After many decades of fire exclusion, the National Park Service has recognized the importance of fire to maintain native plant and animal communities and ecological processes in many ecosystems. The Park Service has developed clear recommendations and guidelines for the use of fire within the National Park System, including the Federal Wildland Fire Management Policy and Program Review (Glickman and Babbitt 1995), Director's Order 18: Wildland Fire Management, and Reference Manual 18: Wildland Fire Management (NPS 2003). These documents outline the important uses of fire and fire management in the National Park System, including "restoring, mimicking, or replacing the ecological influences of natural fire, maintaining historic scenes, reducing hazardous fuels, eliminating exotic/alien species, disposal of vegetative waste and debris, and preserving endangered species"(NPS 2003). With this guidance, numerous NPS units have developed fire management programs based upon resource management objectives, including maintaining the natural role of fire based on historical fire regimes.

Policy of the National Park Service also includes fuels management as an important component of fire management. The Federal Wildland Fire Management Policy and Program Review (Glickman and Babbitt 1995) and the National Fire Plan (2001a) target fuels reduction as a primary goal. In 2002, 2.25 million acres (0.91 million ha) of federal land managed by the Department of the Interior and the USDA Forest Service were treated to reduce hazardous fuels (National Fire Plan 2002). The National Fire Plan's 10-Year Comprehensive Strategy (National Fire Plan 2001b) calls for increases in current levels of fuel treatment, and many NPS units are currently developing large-scale fuel treatment plans, particularly at the wildland and urban interface.

Developing alternative strategies

National Park Service resource and fire managers must weigh the benefits of fire and fire management strategies against the risks of promoting invasive nonnative plant species. Collecting data on how fire management practices promote nonnative plant invasion may provide information necessary to modify existing fire management practices. Policy and guidelines of the National Park Service encourage evaluation and modification of management strategies through an adaptive management approach. For example, the Strategic Plan for Managing Invasive Nonnative Plants (NPS 1996) describes how "Working together, scientists and resource managers must gather sound scientific information, use the information to develop management techniques, monitor the results of the management activities, determine if clearly stated objectives are being met, and modify activities as indicated."

In order to develop information necessary to evaluate fire management strategies, the USGS-BRD Sequoia and Kings Canyon Research Station is conducting research on the role of fire and fire management strategies in the invasion of nonnative plants. One study investigates the role of prescribed fire in the invasion of cheatgrass into Kings Canyon National Park. Another study addresses the role of fuels treatments in the invasion of nonnative plant species throughout California. We hope these studies will provide information that will assist resource managers in modifying existing fire management programs so they will continue to meet their objectives while minimizing the threat of nonnative plant invasion.

USGS study of fire and cheatgrass in Kings Canyon National Park

In the 1980s the National Park Service introduced prescribed burning into ponderosa pine and mixed-conifer forests of Cedar Grove, a large glacially carved canyon in the west end of Kings Canyon National Park, California. Within two decades, nearly all of the Cedar Grove forests had been burned with low intensity surface fires. This ended an unnaturally long period of more than a century of fire exclusion from these forests and was an important step towards restoring a presettlement fire regime. However, during this long period of fire exclusion, a particularly aggressive nonnative annual grass (cheatgrass, *Bromus tectorum*) had established in the Cedar Grove area. Prior to the reintroduction of fire, cheatgrass was most common in disturbance corridors such as trails, roads, and areas of intensive stock use. Unfortunately, these disturbance corridors served as ideal fire lines for prescribed burning, and following prescribed burns, cheatgrass rapidly spread throughout Cedar Grove into large and small fire-caused openings as well as other disturbed sites in the canyon. Alarm over this invasion was sufficient enough to halt indefinitely all further burning in these forests.

In order to investigate the spread of cheatgrass in Kings Canyon National Park, the U.S. Geological Survey has established a research program to better understand the causal basis for cheatgrass invasion and how fire management practices may affect this invasion process. Through funding by the Joint Fire Sciences Program, and with the cooperation of the Sequoia and Kings Canyon National Parks' fire management program, we initiated an intensive experiment to evaluate prescription burning impacts on cheatgrass spread (fig. 1). In this experiment we have manipulated fuel loads, season of burn, shade, and plant nutrients in order to better understand which fire-related variables promote this species. To investigate the effect of season of burn, we conducted prescribed burns after cheatgrass seeds were dispersed in the fall and prior to

Figure 1. A USGS researcher records fire behavior as a prescribed burn moves through a cheatgrass plot in Kings Canyon National Park. A data-logger records above- and below-ground temperatures from thermocouples. USGS PHOTO BY TOM MCGINNIS

cheatgrass seed dispersal in the spring. In order to investigate how fire temperatures affect the seed bank and nutrients in the soil, we continuously measured temperatures above and below ground during prescription burning, using electronic thermometers, or thermocouples. We hope this information will indicate which variables most strongly influence the invasion of cheatgrass, and allow us to provide data to resource and fire managers that will be useful in developing fire management strategies that do not promote the spread of this invasive species, and that may help to control it. Ultimately it must be recognized that "natural" presettlement fire regimes occurred in a landscape lacking the current pallet of alien species. It may turn out that managers will be forced to alter fire restoration objectives in order to accommodate this new landscape.

USGS study of pre-fire fuel manipulation and nonnative plant species

Another study being conducted by the USGS-BRD Sequoia and Kings Canyon Research Station and funded through the Joint Fire Sciences Program addresses the role of fuel breaks in promoting the invasion of nonnative plants. Fuel breaks are generally constructed to change fire behavior, to provide firefighter access, as a starting point for indirect attack on wildland fires, or to contain prescribed fires (Agee et al. 2000). We define fuel breaks as any area specifically treated to reduce fuels, including linear, cleared features, or large, thinned areas with some canopy cover left intact (shaded fuel breaks). Many federal agencies are currently developing large-scale fuels management programs to reduce the spread of unwanted wildland fires, particularly at the wildland and urban interface (National Fire Plan 2001a).

To examine the role of fuel breaks in promoting invasion by nonnative plant species, we are investigating fuel breaks in a range of plant community types across California, including chaparral, mixed woodlands, and coniferous forests. So far we have visited 10 fuel breaks, including several constructed along the wildland and urban interface. We investigated fuel breaks on NPS lands, in addition to fuel breaks constructed by the USDA Forest Service. Our preliminary data indicate that the relative number, cover, and density of nonnative plant species are generally higher on the fuel break than in the surrounding wildlands (fig. 2). However, each site varied greatly in the number and relative dominance of nonnative plants. One site we investigated near Lake Tahoe contained no nonnative plant species, while other sites had as many as 19 nonnative plant species, representing 88% of all plant species encountered on the fuel break. This site-to-site variability suggests that individual site conditions, including environmental and human-caused factors, play an important role in the ability of nonnative plants to invade. We will be investigating additional fuel breaks during the next two years to determine which factors influence invasibility.

Management implications

Our data should indicate what types of fuel breaks are most likely to promote nonnative plants. For example, studies have shown that canopy cover is an important factor in the establishment of nonnative plant species (Rejmanek 1989). We are measuring canopy cover at each of our sites, and we have negatively correlated canopy cover with nonnative plant presence. By determining the relationship between canopy cover and nonnative plant presence in fuel breaks, we hope to develop recommendations for canopy cover prescriptions within fuel breaks

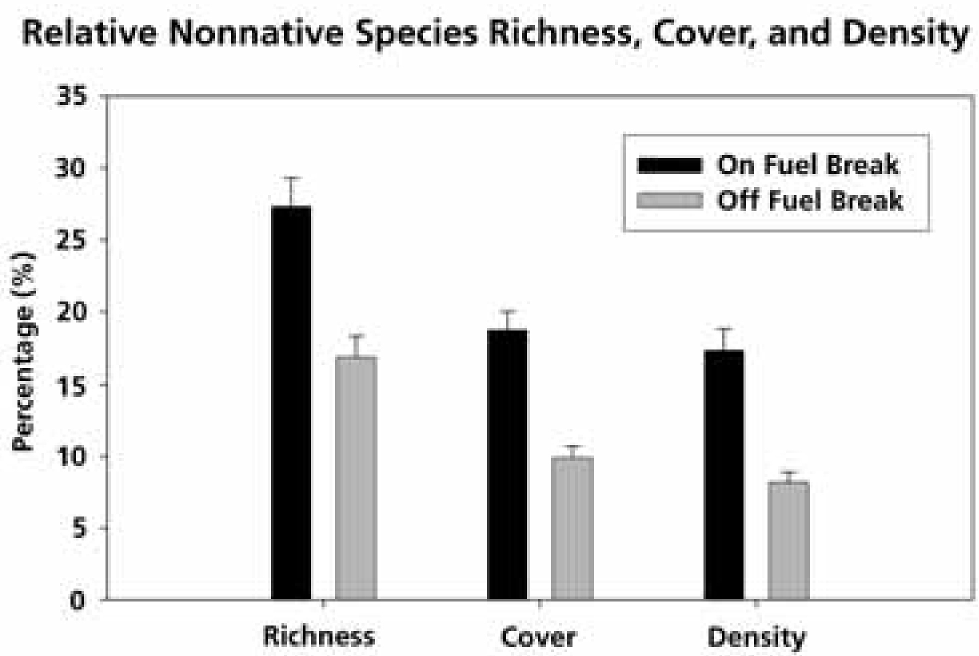


Figure 2. The USGS research compared the relative nonnative species richness, cover, and density on and off a fuel break and found them all to be significantly higher on the fuel break than off it in the surrounding wildlands. A statistical method known as an Analysis of Variance (ANOVA) was used to determine if plots were different on fuel breaks based on the amount of variation present in the data. According to the ANOVA, the probability was less than 0.001 that the differences in nonnative richness, cover, and density on fuel breaks had occurred by chance.

that minimize the threat of nonnative plant invasion.

Fuel break construction and maintenance methods may also influence the invasion of nonnative plants. Some fuel breaks are constructed and maintained primarily through mechanical means (fig. 3), while others may be cleared by hand or through the use of prescribed burning. Many fuel breaks are constructed and maintained using a combination of mechanical clearing and prescribed burning (fig. 4), and in some areas herbicide application is part of the maintenance prescription. In some areas fuel breaks are being constructed through on-site chipping or mastication of fuels. These chipped fuels remain on the ground or are removed by prescribed fire. On-site chipping of fuels possibly reduces germination of nonnative plants. Our data should indicate which of these construction methods and maintenance regimes is least likely to promote nonnative plant invasion.

Much of our analysis will investigate the importance of landscape-level factors, such as proximity to roads and other fuel breaks. Our results should provide fire and resource managers with information necessary to plan the strategic placement of fuel breaks such that the risk of nonnative plant invasion is minimized.

Conclusion

The mission of the USGS Biological Resources Division is to work with others to provide the scientific understanding and technologies needed to support the sound management and conservation of our nation's biological resources. Our research on the role of fire and fire management strategies in the invasion of nonnative plant species is intended to provide fire and resource managers with information to assist them in addressing this complex issue through the development of fire management strategies that reduce nonnative plant invasions.

Figure 3. Researchers examine a fire line constructed by bulldozer in the Shasta Trinity National Forest, near Weaverville, California. USGS PHOTO BY KYLE MERRIAM

Figure 4. This shaded fuel break, called a defensible fuel profile zone, is located in Plumas National Forest, California, and has been mechanically thinned and burned with a prescribed fire. USGS PHOTO BY KYLE MERRIAM

Literature cited

Agee, J. K., B. Bahro, M. A. Finney, P. N. Omi, D. B. Sapsis, C. N. Skinner, J. W. van Wagtendonk, and C. P. Weatherspoon. 2000. The use of shaded fuelbreaks in landscape fire management. Forest Ecology and Management 127:55–66.

D'Antonio, C. M. 2000. Fire, plant invasions, and global changes. Pages 65–93 in H. A. Mooney and R. J. Hobbs, editors. Invasive species in a changing world. Island Press, Covelo, California.

See "The Role of Fire and Fire Management" in right column on page 52

INVASIONS in the sea

By Andrew N. Cohen

Worm attack

Needing a base on the Pacific Coast in 1852, the U.S. Navy went searching for a site that was "safe from attack by wind, wave, enemy, and marine worms" (Lott 1954). The attack worm that worried the Navy was the native Pacific shipworm, *Bankia setacea*. Shipworms bore tunnels in wood, severely damaging wooden pilings and ship hulls.

The Navy built its base in the northern part of San Francisco Bay, where the water is too fresh for the Pacific shipworm. No enemies attacked until an Atlantic shipworm, *Teredo navalis*, which tolerates fresher water than its Pacific cousin, arrived in the bay. The Atlantic shipworm multiplied rapidly and proceeded in 1919 to bore its way through the available habitat, dropping wharves, piers, ferry slips, and other maritime facilities into the water at an average rate of one major structure every two weeks for a period of two years (fig. 1). In current dollars, the worm caused between $2 billion and $20 billion in damage.

Figure 1. The collapse of the Benicia wharf and customs house in San Francisco Bay on October 7, 1920, was caused by the Atlantic shipworm, *Teredo navalis*. FROM R. M. NEILY, HISTORICAL DEVELOPMENT OF MARINE STRUCTURES IN SAN FRANCISCO BAY, IN "FINAL REPORT OF THE SAN FRANCISCO BAY PILING COMMITTEE" (1927).

Marine invaders

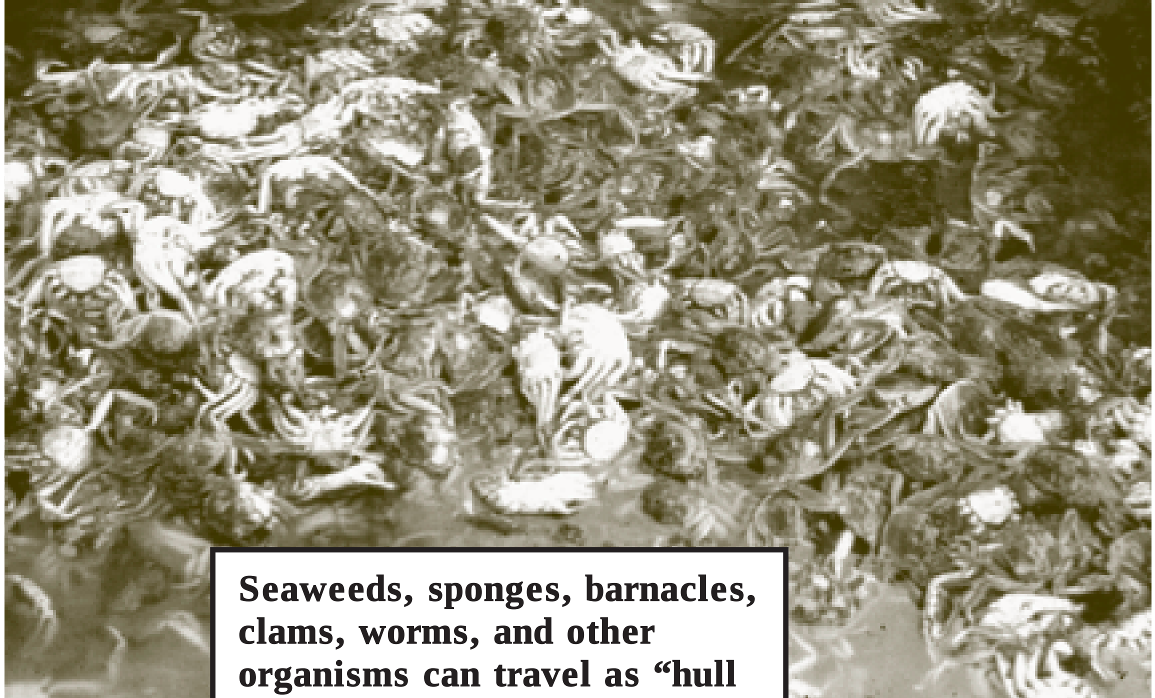
Many recent biological invasions have interfered with human uses of the sea or dramatically altered marine ecosystems.

- The western Atlantic comb jelly *Mnemiopsis leidyi*, a small, gelatinous, planktonic predator, became phenomenally abundant in the Black Sea in the 1990s. It contributed to the collapse of the sea's fisheries by eating up the crustacean zooplankton, a key link in the food web.

- Within a year of its appearance, the Asian clam *Potamocorbula amurensis* was the most abundant clam in the northern part of San Francisco Bay (fig. 2). Researchers estimated that virtually the entire water column was filtered by these clams between once and twice a day, essentially vacuuming the food out of the water. The clams also concentrate selenium in their tissues, so that fish and birds that eat them are accumulating selenium at levels that are known in experimental studies to cause reproductive defects.

Figure 2. Introduced from Asia in ballast water, *Potamocorbula amurensis* had become the most abundant clam in northern San Francisco Bay nine months after it was noticed. ANDREW N. COHEN

- Dinoflagellates are microscopic plankton that sometimes become so abundant that they color the sea as "red tides." These outbreaks can kill invertebrates, fish, and seabirds. Some dinoflagellates produce neurotoxins that accumulate in mussels or clams consumed by humans, causing paralytic shellfish poisoning (PSP). In recent decades, red tides and PSP outbreaks have been reported more frequently around the world and in areas where they were previously unknown. At least some of these (in mainland Australia and Tasmania, France, and probably also New Zealand and Chile) apparently resulted from exotic dinoflagellates discharged in ships' ballast water.

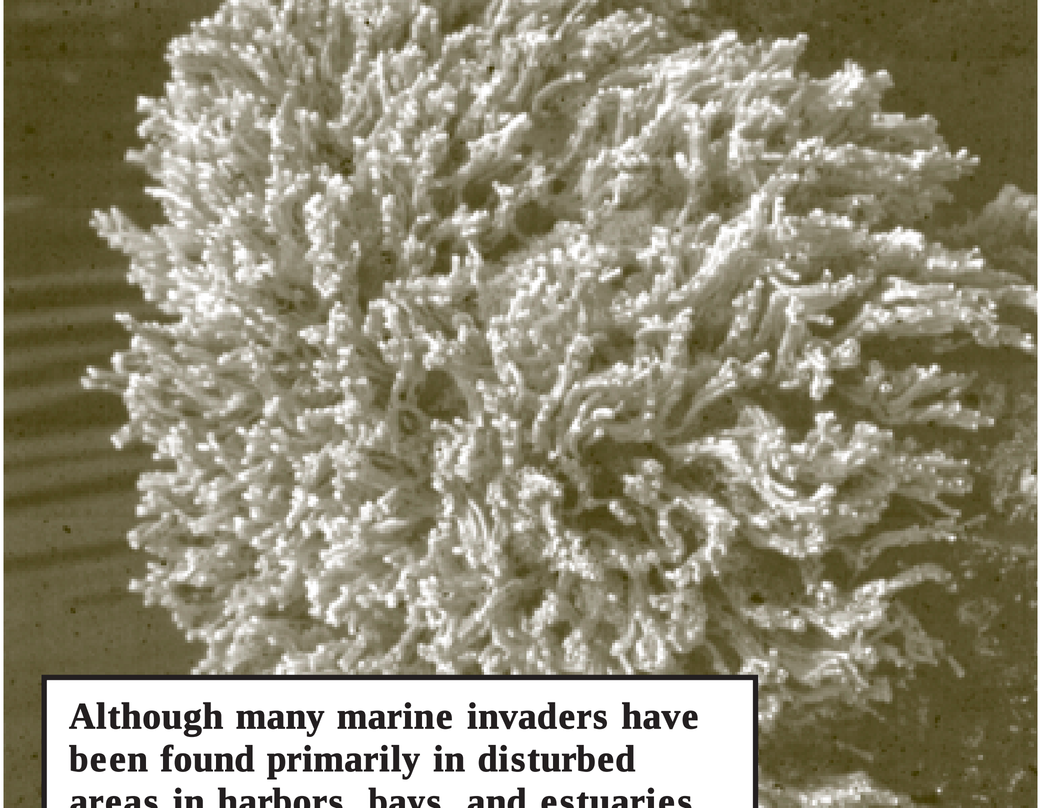


Seaweeds, sponges, barnacles, clams, worms, and other organisms can travel as "hull fouling," attached or clinging to the hulls of vessels, or, like shipworms, burrowed inside wooden hulls.

San Francisco Bay demonstrates the extent to which invasions can transform an ecosystem. More than 175 exotic marine and estuarine species have been identified, including the most common worms, clams, snails, amphipods (a type of small crustacean), and foraminifers (amoeba-like microorganisms) on the bottom of the bay. Japanese zooplankton and European jellyfish have taken over in brackish waters. An Atlantic cordgrass is spreading through the bay's salt marshes, dramatically altering habitat, threatening the existence of native cordgrass, and altering the distribution and populations of marsh-nesting birds. Chinese mitten crabs have colonized the bay, with hundreds of thousands crawling up the rivers in boom years (fig. 3). Exotic species now dominate many of the estuary's biotic communities where they typically account for 40%–100% of the common species, up to 97% of the total number of organisms, and up to 99% of the biomass. And in recent decades they have been coming in faster than ever, with about four new species becoming established each year (Cohen and Carlton 1998).

On the move

Marine invaders are moved around the world by a variety of mechanisms. Seaweeds, sponges, barnacles, clams, worms, and other organisms can travel as "hull fouling," attached or clinging to the hulls of vessels, or, like shipworms, burrowed inside wooden hulls (figs. 4 and 5). Many marine organisms are microscopic plank-



Although many marine invaders have been found primarily in disturbed areas in harbors, bays, and estuaries, ... specific invasion threats to open coastal and offshore areas have been documented, indicating that even these relatively pristine waters [of the National Park System] may be at risk.

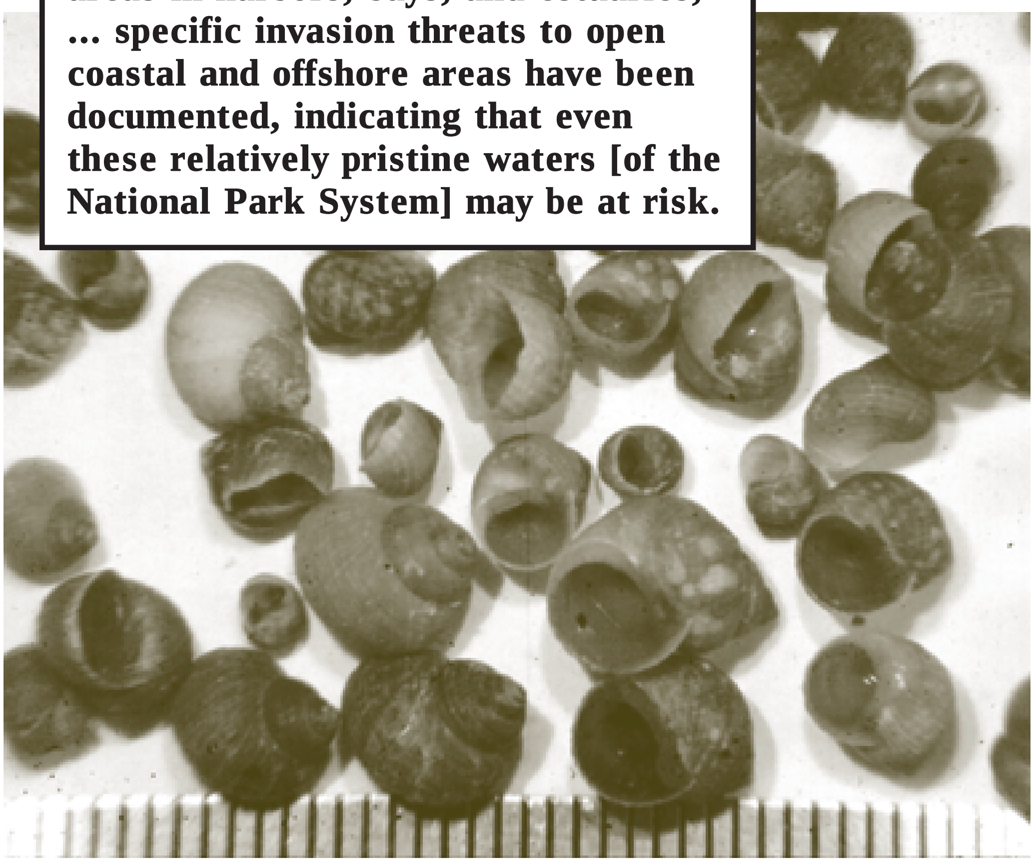


Figure 3, top left. A truckload of Chinese mitten crabs, *Eriocheir sinensis*, being hauled away from the intake screens of the Central Valley Project water diversion in central California.

Figure 4, bottom left. Several species of exotic sea squirts, sponges, and bryozoans are shown growing on a boat hull in San Francisco Bay.

Figure 5, top right. The tubes of a subtropical, hull-fouling and reef-forming polychaete worm, *Ficopomatus enigmaticus,* in San Francisco Bay.

Figure 6, bottom right. The Atlantic periwinkle, *Littorina saxatilis*, arrived in San Francisco Bay with shipments of Maine baitworms. ANDREW N. COHEN (4)

ton that can be carried in a ship's ballast water. Much marine aquaculture is based on exotic species; some of these are intentionally planted in the environment, while others often escape from the facilities in which they are held, sometimes carrying exotic parasites or diseases. Saltwater species are a small but rapidly growing sector of the aquarium industry, and these organisms sometimes escape from commercial facilities or are released into the ocean by their owners when no longer wanted. Several species of marine fish, shellfish, and algae have been released by government agencies into new parts of the world to establish or support fisheries, and some agencies have considered releasing exotic marine organisms as biocontrol agents. Other vectors include the international transport and sale of live marine bait, live seafood, and live organisms for research and education (fig. 6).

Marine invasions and the National Park System

The National Park System includes more than 3 million acres (1.2 million ha) of submerged ocean floor and about 4,500 miles (7,241 km) of ocean coastline. Although many marine invaders have been found primarily in disturbed areas in harbors, bays, and estuaries, and thus may not affect most of the Park Service holdings, within each region specific invasion threats to open coastal and offshore areas have been documented, indicating that even these relatively pristine waters may be at risk.

In the Southeast, individuals and small groups of Pacific lionfish *(Pterois volitans)* have been sighted, photographed, or collected from Florida to North Carolina, with additional records in Bermuda and New York (Whitfield et al. 2002). These probably result from aquarium releases, and the evidence suggests that the lionfish is established and reproducing there. In its native range the lionfish is found on rock and coral reefs down to depths of 164 feet (50 m). Its venomous spines protect it from predators and may pose a risk to divers.

Another notorious aquarium release is the tropical green seaweed *Caulerpa taxifolia* (fig. 7). An aquarium-bred clone of this species became established in the Mediterranean Sea in the 1980s, and now covers about 10,000 acres (4,050 ha). It grows over seagrass beds, rocky reefs, and corals alike, ranging from quiet waters to wave-pounded capes, and from near-surface waters to 295-foot (90-m) depths. Fishing and recreational diving have both suffered. In 1998, I drafted a petition signed by more than 100 scientists, seeking a prohibition on the import and sale of this seaweed in the United States. It was banned in 1999, but was discovered in two California lagoons in the spring of 2000. An eradication effort based on pumping chlorine beneath rubberized tarps laid over the infested areas has cost more than $3 million to date. Coral reefs in Florida, the Virgin Islands, Hawaii, American Samoa, and Guam, and waters north to North Carolina and California, could be vulnerable to invasion.

Also in California, a South African shell parasite, the sabellid worm *Terebrasabella heterouncinata*, widely infested abalone farms and escaped into the environment in at least one site. This parasite can deform and halt the growth of all West Coast abalone species—whose populations are already in rapid decline, with one near extinction—as well as other marine snails. It can invade habitats from intertidal rocky shores to subtidal reefs, where reducing snail populations could alter seaweed communities, thereby affecting habitat and food resources for many other species.

Figure 7. The tropical aquarium seaweed, *Caulerpa taxifolia*, overgrowing a rocky substrate in the Mediterranean Sea near Monaco. ALEX MEINESZ

Atlantic salmon are raised in and regularly escape from fish farms on both North American coasts. More than 100,000 Atlantic salmon escape from Pacific Coast farms per year, and they are now established in the wild in British Columbia (Volpe et al. 2000). Possible impacts on both coasts include competition with native salmon and the introduction of parasites or diseases to which native salmon are not adapted, and in the Atlantic, the genetic pollution of local stocks, leading to loss of fitness.

Finally, following the apparent overharversting of fish and sea urchins in the Gulf of Maine, some rocky reefs down to 66-foot (20-m) depths have become dominated by exotic species, including green and red seaweeds and two species of colonial sea squirts (Harris and Tyrrell 2001). Recently a third exotic sea squirt has been found covering gravel, boulders, and bottom organisms on Georges Bank at depths of 135 to 157 feet (41 to 48 m) (USGS 2004) (fig. 8). In other regions they have invaded, most of these species are typically found only in bays and harbors. Thus, even organisms that are normally considered bay species may be capable of invading open waters under the right conditions.

Managing invasions

Other than local removals of salt-marsh weeds, only two successful eradications of marine invaders have occurred. In northern Australia, a mussel became established in three boat basins connected to the ocean by lock systems; the government closed the locks for three weeks and poured in biocides until everything in the basins was killed (Bax 1999). In southern California, the South African shell parasite discussed earlier was found in the intertidal zone of one cove; approximately 1.6 million intertidal snails were removed, reducing the host density to a level that was too low to sustain the parasite (Culver and Kuris 2000). The *Caulerpa* eradication effort

Figure 8. The European sea squirt *Didemnum* cf. *lahillei* has recently become established in New Zealand, California, and New England, including parts of George's Bank. It is shown covering a rope in Sausalito, California. GRETCHEN LAMBERT

mentioned earlier may ultimately prove to be a third successful example.

However, the interconnectedness of ocean waters, the huge number of easily dispersed young produced by many marine organisms, and the difficulty of locating and treating organisms in subtidal waters make eradication or even significant control of most marine invaders a daunting task. The techniques typically employed on land—applying herbicides and insecticides; trapping, shooting, and poison-baiting animals; and applying the chemical rotenone to ponds or lakes to kill off unwanted fish—are inapplicable or ineffective for most marine organisms. Furthermore, with new invaders arriving at a rapid rate, resource managers could not implement the number of control efforts needed to contain them all *even if* effective methods were available.

Fortunately, there are some things we can do to substantially reduce the transport and release of exotic marine organisms and prevent many of them from arriving in the first place. First, intentional importations and releases should be subjected to rigorous, public review before being allowed and, if allowed, should include precautionary procedures to prevent the accidental introduction of parasites or other associates. These standards have probably been met for the few government releases of exotic marine organisms considered in recent years. However, such standards are not applied to the importation and handling of exotic organisms intended for use in aquaculture, in the aquarium, for live bait, as seafood, or in research or education. An essential step is changing the federal management of imports from the current "dirty list" approach, which allows the importation of any organism unless it is proven to be dangerous, to a "clean list" approach in which exotic organisms proposed for importation under a set of procedures must be shown to be safe (as recommended by the U.S. Fish and Wildlife Service 30 years ago).

Second, we must reduce as far as possible the number of exotic organisms unintentionally transported with ships in ballast water and hull fouling. As of this writing, 30 years after the United Nations first recognized the ballast water problem, federal agencies still do not bar ships from dumping exotic organisms into U.S. marine waters. This is not because the problem is especially complex: killing or removing organisms that are contained in tanks of water is simple compared to most environmental challenges. And though several existing federal and state laws could limit the discharge of exotic organisms in ballast water, agencies have not made use of them (Cohen and Foster 2000). Controlling the transport of organisms attached to the hulls of ships is more complicated, but maintenance requirements targeting the most heavily fouled vessels might be feasible and reasonably effective.

The big picture

The organisms that inhabit coastal waters are distributed in distinct bioregions separated by continents, by areas with different water temperatures, and by reaches of deep ocean inimical to coastal life. Each of these coastal bioregions, developing in relative isolation from the others, has evolved its own unique assemblage of native organisms. These native assemblages are increasingly threatened by the transport of species across the barriers that separate bioregions. In most cases, it will be difficult or impossible to control the populations or stop the spread of exotic organisms after they have crossed these barriers and become established in a new bioregion. Instead, the preservation of distinctive ecologies in waters of the National Park System and other marine protected areas will require a vigorous defense of natural bioregional boundaries by regulating the activities that transport organisms across them.

Literature cited

Bax, N. J. 1999. Eradicating a dreissenid from Australia. Dreissena! 10(3):1–5.

Cohen, A. N., and J. T. Carlton. 1998. Accelerating invasion rate in a highly invaded estuary. Science 279:555–558.

Cohen, A. N., and B. Foster. 2000. The regulation of biological pollution: preventing exotic species invasions from ballast water discharged into California coastal waters. Golden Gate University Law Review 30(4):787–883.

Culver, C. S., and A. M. Kuris. 2000. The apparent eradication of a locally established marine pest. Biological Invasions 2:245–253.

Harris, L. G., and M. C. Tyrrell. 2001. Changing community states in the Gulf of Maine: Synergism between invaders, overfishing, and climate change. Biological Invasions 3(1):9–21.

Lott, A. S. 1954. A long line of ships: Mare Island's century of naval activity in California. U.S. Naval Institute, Annapolis, Maryland.

U.S. Geological Survey (USGS). 2004. USGS Woods Hole Science Center Web site on "Marine invasive species: Didemnum lahillei, a colonial tunicate" available from http://woodshole.er.usgs.gov/project-pages/stellwagen/didemnum/index.htm (last modified and accessed 15 April 15 2004).

Volpe, J. P., E. B. Taylor, D. W. Rimmer, and B. W. Glickman. 2000. Evidence of natural reproduction of aquaculture-escaped Atlantic salmon in a coastal British Columbia river. Conservation Biology 14(3):899–903.

Whitfield, P. E., T. Gardner, S. P Vives, M. R. Gilligan, W. R. Courtenay, G. Carleton-Ray, and J. A. Hare. 2002. Biological invasion of the Indo-Pacific lionfish *Pterois volitans* along the Atlantic Coast of North America. Marine Ecology Progress Series 235:289–297.

About the author

Andrew N. Cohen is an environmental scientist and the director of the Biological Invasions Program at the San Francisco Estuary Institute, 7770 Pardee Lane, Oakland, CA 94621. He can be reached at 510-746-7367 and acohen@sfei.org.

Under water and out of sight:
Invasive fishes in the United States
Implications for national parks

By Walter R. Courtenay, Jr., and Pam L. Fuller

The National Park Service (NPS) has been concerned with introductions of nonnative (foreign and domestic transplants) species in park areas since 1933 (Dennis 1980). Such introductions were recognized then as potential threats to maintaining areas under NPS jurisdiction as undisturbed as possible. Most activities since then to remove, reduce, or control introduced species in the National Park System have targeted terrestrial species, with only limited focus on aquatic organisms.

Shortly after Yellowstone was established as the first national park in 1872, the U.S. fish commissioner assigned an ichthyologist to assess it for native fishes and advise what nonnative fishes should be introduced for angling purposes (Jordan 1891). For many decades thereafter, NPS policy was to stock nonnative fishes in many national park units for sport fishing. The policy was challenged in the 1940s (Hubbs 1940, Hubbs and Wallis 1948, Hubbs and Lagler 1949) and later (Miller 1963) when sport fishes were recognized as a threat to native fishes in the national parks. What was unimagined then was that nonnative fishes introduced outside park boundaries would invade shared waters as new introduction pathways evolved. For example, visitors to Everglades National Park, Florida, taking time to look into water at Anhinga Trail now see more fishes from Africa, Central and South America, and Asia than native fishes.

In 1989 Courtenay reported at least 20 species of exotic (foreign) fishes known or reported to be established as reproducing populations in waters within or bordering units of the National Park System. That number did not include fishes native to the United States that had been transplanted and became established beyond their native ranges of distribution. Had U.S. transplants been included, the total number of nonnative fishes within or near the national parks would have been vastly higher. The National Park Service maintains a database of nonnative fishes in natural resource parks based on voluntary park input that presently includes 118 species of which 33 are exotics (James T. Tilmant, personal communication, 2003). The data suggest the probability that no national parks are without introduced fishes (fig. 1)

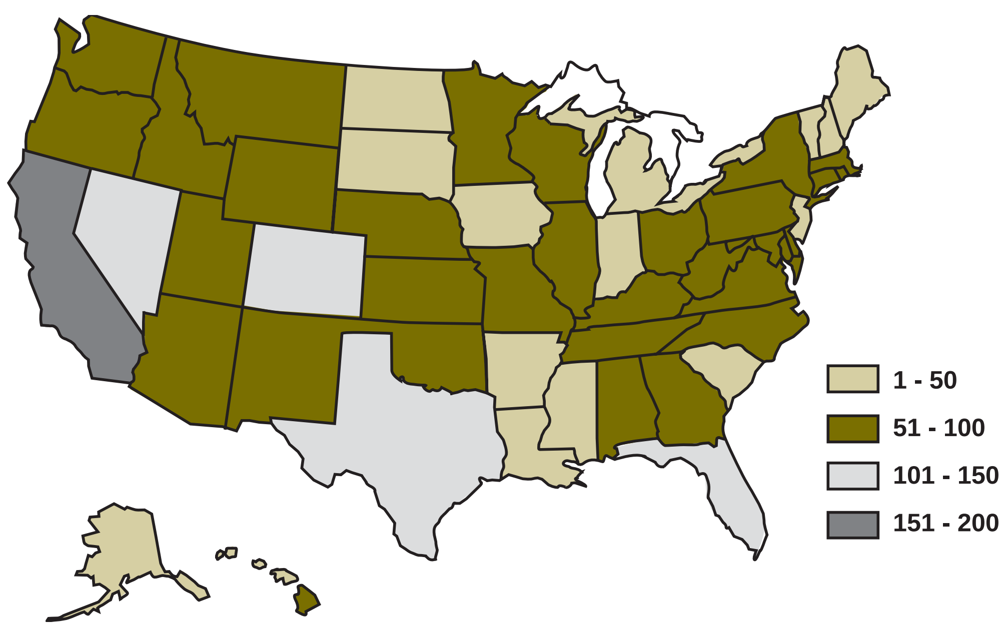


Figure 1. Number of fish taxa introduced by state, including both established and non-established populations. USGS NONINDIGENOUS AQUATIC SPECIES DATABASE, 2004

Fuller et al. (1999) reported nonnative fishes as having been introduced to all 50 states, with 536 taxa found beyond their native ranges (fig. 2). Although many failed to become established, those fishes came from all continents, including North America, except Antarctica.

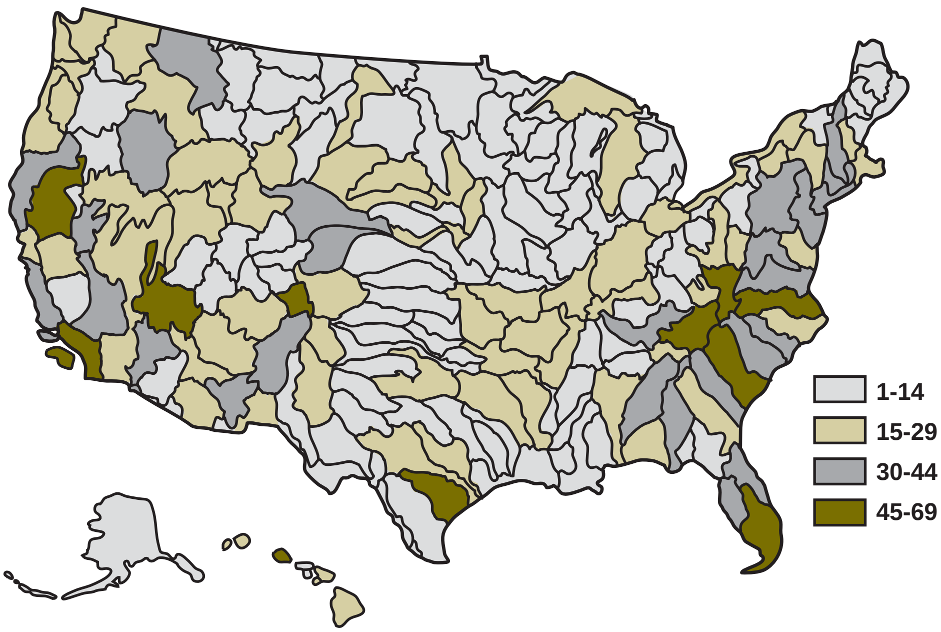


Figure 2. Approximate number of exotic and transplanted native fish taxa by drainages (USGS 4-digit hydrologic unit code). Includes established and non-established introductions. AFTER FULLER ET AL. 1999.

Pathways of introductions

Fishes are moved to ecosystems and habitats novel to them via a variety of pathways (fig. 3). These include authorized introductions for sport fishing, forage enhancement for sport fishes, or for biological control. Unauthorized intentional introductions have also occurred for sport fishing and through the release of bait fishes by anglers, unwanted "pet" fishes by aquarists, and, in a few instances, research fishes by scientific or maintenance personnel. Some introductions may have been made in hopes of establishing new food resources for people. In recent years, live food fishes from abroad, usually Asia, have been imported for sale in fish markets. These live food fishes are often sold at or near sexual maturity, and some have been released for unknown reasons into natural waters.

> Fishes are moved to ecosystems and habitats novel to them via a variety of pathways .... [that] include authorized introductions for sport fishing, forage enhancement for sport fishes, or for biological control.

Unintentional introductions have occurred through escapes from food-fish aquaculture facilities and aquarium fish farms, stock contamination and ballast water discharges from ships. Canals connecting separate drainage basins also facilitate introductions of fishes. For example, construction of the Welland Canal in the late 1800s and subsequent modifications of its design in the early 1900s allowed the predaceous sea lamprey *(Petromyzon marinus)* access into the upper Great Lakes from Lake Ontario. This resulted in devastation of native lake trout *(Salvelinus namaycush)* in waters including Lake Superior where Isle Royale National Park is located.

Of the pathways mentioned, the largest number of introductions that have resulted in established, reproducing populations, many of which became invasive, are sport-fishing related (Fuller et al., 1999). Establishment resulted from deliberate stocking of angling species, providing forage fishes to enhance survival of those species, and releases of bait fishes. Fishes stocked for sport angling are always predators, for example, trout. Rainbow trout *(Oncorhynchus mykiss)*, native to extreme western Canada and the northwestern United States west of the Cascade Range, have been established in Great Smoky Mountains National Park for more than a century; brook trout *(Salvelinus fontinalis)*, native to north-central, northeastern, and southeastern states, occur in several western units of the National Park System, results of intentional introductions of sport species. In Great

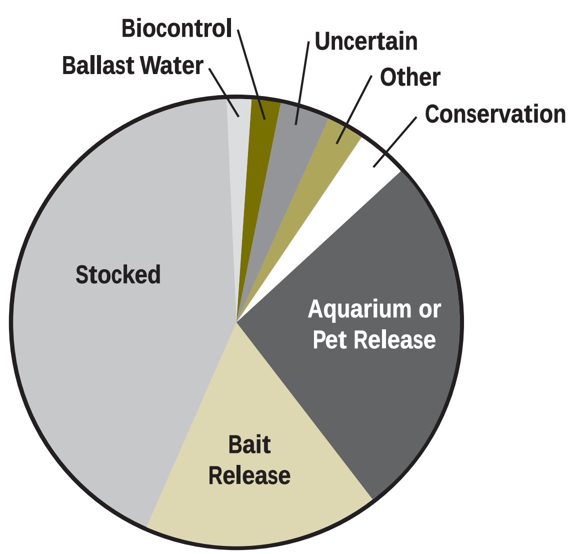


Figure 3. Methods of introduction for fishes nationwide. AFTER FULLER ET AL. 1999.

In Great Smoky Mountains National Park, rainbow trout have caused substantial declines of native brook trout.

Smoky Mountains National Park, rainbow trout have caused substantial declines of native brook trout. In addition, brown trout *(Salmo trutta)*, native to northern Eurasia and north Africa, occur in many national park areas and compete with native trouts. Lake trout, native to northern Canada, Alaska, New England states, and the Great Lakes basin, recently introduced illegally in Yellowstone National Park for sport, have become established in Yellowstone Lake, threatening native Yellowstone cutthroat trout *(Oncorhynchus clarki bouvieri)*. The lake trout has been present for several decades in Flathead Lake, Montana, and has spread into several of the large glacial lakes along the western side of adjacent Glacier National Park. Where lake trout have become established in these lakes they have virtually eliminated native cutthroat and bull trout *(Salvelinus confluentus)*. They have also replaced native cutthroat trout in deep lakes of the Rocky Mountains including Grand Lake, which borders the western edge of Rocky Mountain National Park, Colorado.

Reasons for concern

Just because introduced species are under water and out of sight does not mean they are not causing problems! Introduced fishes present a spectrum of ways in which ecosystems and habitats may be altered. Direct predation, especially on invertebrates, is one way, particularly where native fishes are few in number and especially in waters historically devoid of native predators. Competition for food, space (particularly spawning areas), and different behavioral patterns can also negatively impact native fish faunas. Food webs can be altered, affecting not only fishes but also invertebrates and plants upon which fishes depend. (See the article on pages 68–70 about impacts of nonnative fishes on two salamander species in Mount Rainier and North Cascades National Parks.) Additionally, transplanted species are likely to hybridize with related native fishes, causing pollution of native fish gene pools, which in turn results in the demise of endemic native species. And introduced species carrying parasites or diseases are always a threat because they could negatively affect native fishes, at worst drastically rearranging species composition.

Just because introduced species are under water and out of sight does not mean they are not causing problems!

The degree to which native fishes and habitats are impacted depends on which species are introduced and the native biodiversity of the affected ecosystem. Although some people believe that introductions increase biodiversity, the increase is artificial. Moreover, "good" or "bad" aspects of introductions are subjective. Those who profit financially from introductions or see introductions as enhancing aquatic habitats view the world differently from conservation biologists who believe better management and restoration of disturbed habitats is the wise and safe approach.

Who regulates introductions?

Fish introductions are generally regulated by state agencies; however, the National Park Service regulates introductions in the National Park System. The federal government has no authority regarding introductions except on federal lands, but it does have authority over importation into the United States and interstate transportation. That authority exists under the Lacey Act of 1900 and its subsequent amendments. For example, transportation of a species into states that prohibit possession of live individuals of that species is a violation of the Lacey Act. The act also contains an "injurious wildlife" provision under which the U.S. Fish and Wildlife Service, after proposing to list species as injurious followed by a period of public review and commentary, can prohibit importation and interstate transport of listed species. The only fishes listed to date as injurious under the act are salmonids (salmons and trouts) and their eggs (to prevent potential introduction of salmonid diseases), walking catfishes (Family Clariidae), and, most recently, snakehead fishes (Family Channidae). Black carp *(Mylopharyngodon piceus)* is under review, and silver carp *(Hypophthalmichthys molitrix)* and bighead carp *(H. nobilis)* may be added for listing.

Transportation of a species into states that prohibit possession of live individuals of that species is a violation of the Lacey Act.

Virtually all states prohibit introduction or release of nonnative fishes without a permit. The state permitting agencies, however, always retains the right to make introductions without seeking permission from any federal authority and without peer review by other states. Traditionally most state game and fish agencies also have had authority to control what fishes are imported into a state. In an effort to prevent unwanted species introductions, many states have developed lists of fishes that are prohibited from importation to state waters. However, these lists often differ between states. Thus, permissible importation and release of a species into state waters presents the potential for that species to spread via interconnected drainage basins into a neighboring state that prohibits the same species. Moreover, commercial aquaculture has recently sought exemption from state game and fish agency regulations by having aquaculture placed under jurisdiction of state agriculture departments. This trend avoids regulation of importation or introductions by agencies that historically have had this authority and a legal commitment to conserve state natural resources.

The "bottom line" for the National Park Service

In many national parks fishes are being monitored and managers are developing policies for the control of unwanted species to the extent that their budgets allow. Unless park managers aggressively work to prevent introductions of new exotics, park areas will continue to receive introductions. Some of the unwanted species will become invasive, while others will fail or become only temporary park residents. That is the "*bad news*."

The "*good news*" is that since 1968, National Park Service policy has been to disallow fish stocking in the national parks and to prohibit introductions of nonnative fishes. Additionally, the National Park Service is actively removing nonnative fishes in several park units and, in some areas, introductions of native species are being used to reestablish natives that have declined (James T. Tilmant, personal communication, 2003). For example, Yellowstone National Park conducts a gill-netting operation on Yellowstone Lake in an effort to control nonnative lake trout (see page 23). At Great Smoky Mountains National Park, volunteers and part staff have removed nonnative rainbow trout. In Great Basin National Park, resource managers have been working to expand the range of native Bonneville cutthroat trout *(Oncorhynchus clarki utah)* in the park. Similar projects are being planned or are under way in other park units.

In addition to these efforts, the National Park Service is better equipped than any federal agency to educate the public as to the dangers of introductions of nonnative species, terrestrial or aquatic. Many personnel have the educational background, experience, and training to point out not only the many wonderful, natural features of the national parks, but also that introduced species have potential to cause dramatic changes to those and other systems. Park visitors, including those from other nations, commonly take advantage of the educational programs of the National Park Service to learn about what they assume to be "natural places." The opportunity for the Park Service to warn them about the consequences of introductions should not be missed.

Acknowledgments

We thank James T. Tilmant, NPS Water Resources Division, Fort Collins, Colorado, for providing helpful information on current NPS policy on fish introductions and for sharing data on introduced fishes in national parks. We are also grateful to James D. Williams, USGS Center for Aquatic Resources Studies, Gainesville, Florida, for his helpful comments on the manuscript.

Literature cited

Courtenay, W. R. 1989. Exotic fishes in the National Park System. Pages 237–252 in L. Thomas, editor. Proceedings of the 1986 Conference on Science in the National Parks. Volume 5. Management of exotic species in natural communities. U.S. National Park Service and George Wright Society, Washington, D.C.

Dennis, J. G. 1980. National Park Service research on exotic species and the policy behind that research: an introduction to the Special Session on Exotic Species. Pages 241–250 in Proceedings of the Second Conference on Scientific Research in National Parks, 26–30 November 1979, San Francisco, California. National Park Service, Washington, D.C.

Fuller, P. L., L. G. Nico, and J. D. Williams. 1999. Nonnative fishes introduced into inland waters of the United States. Special Publication 27. American Fisheries Society, Bethesda, Maryland.

Hubbs, C. L. 1940. Fishes from the Big Bend region of Texas. Transactions of the Texas Academy of Science 23:3–12.

Hubbs, C. L., and O. L. Wallis. 1948. The native fish fauna of Yosemite National Park and its preservation. Yosemite Nature Notes 27(12):131–144.

Hubbs, C. L., and K. F. Lagler. 1949. Fishes of Isle Royale, Lake Superior, Michigan. Papers of the Michigan Academy of Science, Arts, and Letters 33:73–133.

Jordan, D. S. 1891. A reconnaissance of the streams and lakes of the Yellowstone National Park, Wyoming, for the purposes of the U.S. Fish Commission. Bulletin of the U.S. Fish Commission 9:41–63.

Miller, R. R. 1963. Is our underwater life worth saving? National Parks Magazine 37(188):4–9.

About the authors

Walter R. Courtenay, Jr., Ph.D., is professor emeritus of zoology, Florida Atlantic University, Boca Raton, Florida, and research fishery biologist with the U.S. Geological Survey, Center for Aquatic Resources Studies, 7920 N.W. 71st Street, Gainesville, FL 32653-3071. He can be reached at 352-264-3519, or by e-mail: walter_courtenay@usgs.gov.

Pam L. Fuller, M.S., is a biologist, also with the USGS Center for Aquatic Resources Studies, and can be reached at 352-264-3481, or by e-mail: pam_fuller@usgs.gov.

Ecological effects of animal introductions

NPS PHOTOS

at Channel Islands National Park

By Kathryn McEachern

The California Channel Island archipelago is sometimes called the Galapagos of North America because of its high number of endemic species and unusual plant and animal community assemblages. Twelve islands make up the island group, scattered from near Point Conception, in California, USA, to the offshore waters near Baja California, Mexico. Channel Islands National Park manages the five northernmost islands: Anacapa, Santa Cruz, Santa Rosa, San Miguel, and Santa Barbara. The remaining islands are owned and managed by the U.S. Navy, private conservation or recreation organizations, or Mexico.

Natural environmental factors have played a prominent role in the evolution of the plants and animals of all the islands. The islands vary widely in geology, topographic complexity, and elevation. The climate of the islands to the north is influenced by the colder waters of the Humboldt Current coming from the north Pacific, while the southern islands lie in currents bringing warm waters from the south. Island size varies from less than a square mile to nearly 50 square miles (2.6–129 sq km), and the islands lie between 15 and 60 miles (24 and 97 km) offshore. Some of the islands remain shrouded in dense fog for many days of the year, while others have fog-free areas in their interiors. These and other natural factors interplay to influence the development of a flora and fauna high in local endemism, with unusual combinations of mainland and endemic species in the plant and animal communities, and a high degree of diversity among the islands. Yet, all of the islands have been used for fishing, ranching, hunting, and other forms of development and recreation in the past. As a result, intentional and accidental introductions of animals and plants to all of the islands have occurred, with pervasive effects on nearly all aspects of island ecology. Channel Islands National Park was established to preserve, protect, and interpret the natural and cultural resources of the northern islands. The National Park Service and USGS–Biological Resources Division (USGS–BRD) have taken steps to understand the ecological effects of these invasions through the establishment of ecological monitoring and research programs, and the National Park Service is moving forward with conservation management for recovery and restoration.

Some of the islands remain shrouded in dense fog for many days of the year, while others have fog-free areas in their interiors.

Animal introductions

The early economy of southern California developed around livestock production for hides, tallow, and wool; and the islands were among the first areas to be developed in the state. By the 1880s sheep ranches were established on the larger islands of Santa Cruz, Santa Rosa, and San Miguel for the production of wool. Livestock operations were sustained through the mid- to late-1900s (fig. 1). Most livestock were introduced for wool or meat production, some were brought to the islands for recreational hunting, and others arrived by accident. The ranches on Santa Rosa and Santa Cruz were productive operations for more than a century. The Santa Rosa operation was converted to cattle in the early 1920s; deer, elk, and European boar were introduced for hunting in 1930; and deer and elk hunts still occur on Santa Rosa under a special use permit today. On Santa Cruz, sheep and cattle were run simultaneously on different parts of the island. European boar and turkeys were introduced for hunting in the 1930s. Each of these two ranches had small herds of horses bred on the islands, and descendants of those herds persist on those islands as small managed groups today. A series of droughts in the early 1900s halted sheep production on San Miguel Island in 1949. Several donkeys were introduced during the filming of a Hollywood movie in the 1960s, and they developed into a small herd over nearly 12 years before being removed by the National Park Service.

Although Anacapa and Santa Barbara Islands are only about one square mile (2.6 sq km) in area each, and lack permanent water, sheep were grazed there for about two decades beginning in the early 1900s. The U.S. Life Saving Service developed a lighthouse operation on Anacapa in 1937, with quarters for up to five families on the island. Black rats *(Rattus rattus)* found their way to Anacapa and San Miguel in the 1930s, but they have not developed populations on any of the other park islands. House cats were brought to Santa Barbara Island by the sheep-farming operation in the 1920s. From 1942 to 1947, Santa Barbara Island was used as an aircraft early warning outpost. The U.S. Navy released Belgian hares and New Zealand red rabbits as an emergency food source for the staff there, in the event that they became stranded on the island during the war. When the Navy left Santa Barbara Island, the rabbits remained.

All of these ranching operations included some farming, along with the cultivation of landscape plants. Hay pastures were plowed and planted on all but Anacapa Island. Vineyards were cultivated for production of a Santa Cruz Island red wine and table grapes for about 30 years in the late 19th and early 20th centuries. Olives were planted in the 1930s, and European honeybees were introduced for honey production around 1920. Ornamental eucalyptus, Italian stone pines, figs, and citrus were grown near the Santa Cruz Island ranch buildings, along with garden vegetables and flowering plants, throughout the ranching era. The U.S. Coast Guard acquired the Anacapa lighthouse operation in 1947, and planted an alien mat-forming figwort *(Malephora crocea)* in the ice-plant family for erosion control around the buildings, roads, and trails. Farming on Santa Barbara included plowing and planting of nearly one-half of the island in oats and potatoes.

Alien plant invasions

From an ecological perspective these historical operations can be seen as a powerful and prolonged disturbance that changed the environmental context for the native flora and fauna, opening pathways for the invasion of island vegetation by nonnative plants. Ranching and farming altered soil structures and opened sites for the establishment of nonnative plants, brought alien plants to the islands on the animals and

Ranching and farming altered soil structures and opened sites for the establishment of nonnative plants....

Years:	1800--------------1850--------------1900-------------1950-------------2000
Anacapa Island	1853 Black rats — 2001
Santa Cruz Island	1830 Cattle — 1989
	1830 Horses — 2004+
	1853 Sheep — 1999
	1853 Pigs — (planned) 2006
Santa Rosa Island	1844 Sheep — ~1950
	1844 Cattle — 1999
	1844 Horses — 2004+
	1853 Pigs — 1993
	1881 Mule deer — (planned) 2011
	~1930 Elk — (planned) 2011
San Miguel Island	1800's Black rats — 2004+
	~1950 Donkeys 1975
Santa Barbara Island	1926 Rabbits — 1982
	1880's Cats — 1978

Figure 1. A timeline of animal production on the northern Channel Islands. *SOURCES:* SUMNER 1958, JUNAK ET AL. 1995, LOMBARDO AND FAULKNER 1999, LIVINGSTON 2003

equipment, introduced vectors for the spread of nonnative seeds, changed native habitats used by island fauna, and replaced native plant cover with commercial crops. The results are apparent in the vegetation today.

The pre-ranching land cover of the islands was most likely a matrix of upland native scrub, riparian woodland, and coastal bluff and dune scrub, interspersed with small, native grass openings. Now, between 35% and 75% of each island is occupied by alien grasslands dominated by Mediterranean annual grasses, primarily in the genera *Bromus*, *Hordeum*, *Vulpia*, and *Avena*. Native plant communities are infiltrated with trails and erosion scars, or they are reduced to small, remnant stands on steep slopes inaccessible by ungulates (fig. 2). Understories of the fragmented native shrub communities, particularly coastal sage scrub, island chaparral, island woodlands, riparian areas, and coastal bluff scrub stands, have been invaded by the alien grasses dominant in other areas. One of the most pervasive effects of herbivory has been the widespread replacement of shrub cover by annual grasses. This reduction in vegetation height from 1 to 2 meters for shrubs to several centimeters for grasses has resulted in a great reduction in fog drip, a major source of water for island plants (Ingraham and Matthews 1995). Not only do the grasses compete directly for water with germinating seedlings of native plants, they also effectively reduce the amount of water available in the system for native plant growth.

This conversion of the vegetation from one type to another has had grave consequences for some of the endemic island taxa, which depend upon habitats no longer present.

This conversion of the vegetation from one type to another has had grave consequences for some of the endemic island taxa, which depend upon habitats no longer present. At least one native songbird is extirpated from the northern islands. An endemic lizard *(Xantusia riversiana)* that depends on boxthorn *(Lycium californicum)* cover is endangered. Slightly more than one-quarter of the 775 plants on the islands are not native to California or the islands. Botanical surveys show that sixteen plant taxa are thought to be lost from the islands

Figure 2. Remnant stands of coastal sage scrub in alien island grassland, Santa Rosa Island, with San Miguel Island in the background. NPS PHOTO BY SARAH CHANEY

(Junak et al 1997), 14 taxa are listed as federally endangered or threatened, and 74 more are considered rare or of special concern. Channel Islands Vegetation Monitoring Program data show that nearly half of the plant cover on transects is nonnative (Johnson and Rodriguez 2001).

Cascading ecological effects

The effects of long-term predation, competition, herbivory, and trampling by nonnative animals pervade many levels of ecological organization on all of the Channel Islands. Channel Islands National Park and USGS–BRD scientists conduct a monitoring and research program that describes current conditions, tracks changes in terrestrial and marine systems, and investigates specific problems detected through monitoring efforts. Results provide information on conservation management options. Monitoring and research data show direct effects on guilds of native animals and individual plant taxa. Indirect effects are seen in the fecundity and mortality rates of individual native taxa persisting in altered environmental conditions.

Direct effects

Perhaps the most readily documented effects of sustained disturbance are those related to predation and herbivory. In several instances, data show reduced fecundity and higher mortality as the direct result of feral animal use. After arriving on Anacapa Island in the 1930s, black rats grew in number slowly for many decades. Population declines were seen in nesting seabirds, coupled with high rates of rat predation on eggs (Hunt et al. 1980, McChesney et al. 2000). Seabird monitoring data showed predation rates as high as 90% on the eggs of Xantus's murrelets *(Synthliboramphus hypoleucus)*, which likely contributed to murrelet population declines documented by USGS–BRD research throughout the southern California Bight (Hamer and Carter 2002). In 2001–2003, Channel Islands National Park worked with the Island Conservation and Ecology Group to eradicate rats from the island using aerial applications of a rodenticide. Monitoring data show immediate responses in increased lizard density, much lower murrelet egg predation rates, and higher fledging success in nesting seabirds (Whitworth et al. 2003).

Botanical demographic research conducted by NPS scientists (Clark 1989) identified rabbit herbivory as a major factor in population decline in the Santa Barbara Island live-forever *(Dudleya traskiae)*, and the plant was listed as endangered in 1984 (fig. 3). The National Park Service conducted a rabbit eradication campaign 1980–1981. Subsequent live-forever population censuses show recovery of individual plants, seed production, and the establishment of juveniles, in a reversal of declining trends (McEachern et al. 2003 unpublished data). Similar studies of giant coreopsis *(Coreopsis gigantea)* soon after rabbit eradication on Santa Barbara Island demonstrated the positive demographic effects of reduced rabbit herbivory on plant stems, roots, and seedlings (Salas 1990.) In each of these instances, data showing direct and detrimental effects of an introduced animal on a particular native species were used to justify and obtain funding for animal eradication. In both instances, subsequent studies are showing positive effects on populations of other organisms in the island ecosystems. Such eradications benefit more than just the target species that served as the clear indicators of population losses from predation and herbivory by nonnative animals.

Figure 3. Santa Barbara Island live-forever *(Dudleya traskiae)*, an endemic plant listed as endangered because of the effects of rabbit predation. PHOTO COURTESY OF CHARLES DROST

Indirect effects

Indirect effects of the sustained ranching activities on the islands are clearly demonstrated by the Channel Islands monitoring and research programs, too. Soft-leaved island paintbrush *(Castilleja mollis)* is an endangered plant that occurs in only two sites on Santa Rosa Island. Population demography data collected in the 1990s showed that the plant was in a slow decline, related partially to trampling and herbivory by cattle, deer, and elk that reduced seed production and increased individual plant mortality (McEachern and Chess 2000). Cattle were removed from the island in 1998, and deer and elk are culled semi-annually in the island paintbrush areas. However, demographic data show that populations of soft-leaved island paintbrush still do not include enough new plants germinating from seed for population expansion and recovery. Experiments show that annual production of viable seed is good, and germination rates are more than 80% in the greenhouse. Field outplanting experiments show that seedlings grow when planted within stands of coastal bluff scrub, but not when planted in nonnative annual grass openings in the scrub communities (McEachern et al. 2003). The coastal bluff scrub habitat where the paintbrush grows is highly fragmented, with small patches of scrub widely scattered within a matrix of annual grassland. The paintbrush is unlikely to recover until the coastal bluff scrub recovers a more continuous canopy that allows seeds to fall into hospitable habitats for germination and survival. This is a case where the indirect effects of habitat fragmentation and annual grass invasion compound the problems of higher plant mortality and reduced annual seed output brought on by herbivory and trampling.

The indirect effects of habitat fragmentation and annual grass invasion compound the problems of higher plant mortality and reduced annual seed output brought on by herbivory and trampling.

Perhaps the most compelling case of indirect effects of development on island ecosystems is demonstrated in the island fox *(Urocyon littoralis)*. The fox is a diminutive relative of the mainland grey fox *(Urocyon cinereoargenteus)*, with different endemic subspecies on 6 of the 12 islands in the Channel Islands archipelago (fig. 4). Monitoring data showed drastic island fox declines over a five-year period on three national park islands in the 1990s (Coonan 2001), and subsequent research (Roemer et al. 2001) demonstrated that the proximal source of the problem is predation by nonnative golden eagles *(Aquila chrysaetos)*. Bald eagles *(Haliaeetus leucocephalus)* were native to the islands, and they excluded the golden eagles through aggressive competition for nesting and roosting sites. Bald eagles feed mainly on fish. The bald eagles disappeared from the islands more than a decade ago because of high DDT bio-accumulation rates in their marine prey that rendered the eagle eggs too soft-shelled for survival. As a result, golden eagles have taken up residence on Santa

Figure 4. The island fox has suffered population declines in the California Channel Islands. NPS PHOTO BY BILL EHORN

Cruz Island where they find an ample food base in young piglets, another introduced feral animal. Fox hunting is made easier for the eagles on Santa Cruz, Santa Rosa, and San Miguel Islands where annual grasslands have displaced the native shrub cover used by foxes to avoid avian predators.

This complex problem is being resolved under the guidance of a team of biologists (Coonan 2001), by simultaneously removing golden eagles and feral pigs from Santa Cruz, and reintroducing bald eagles to the northern islands, while protecting the foxes in a captive-breeding program. Pig eradication is complicated by acres of dense cover of monotypic stands of nonnative fennel *(Foeniculum vulgare)*. The fennel established in the Central Valley vineyards when Santa Cruz Island wine production ceased, and it has invaded adjacent scrub where it is an aggressive competitor for light and water (Beatty and Licari 1992). Thus, an aggressive fennel eradication program is a first step in the pig eradication campaign, planned for 2003–2008. Recovery of scrub habitat for the foxes is so far a passive effort; research is under way to investigate ways to encourage the reestablishment of native plants on the islands (e.g., Corry and McEachern 2000, Levine et al. 2002, Carroll et al. 2003, Loeher 2003, and Stratton 2003.)

Restoration and recovery

Changes wrought during the ranching era were widespread and pervasive, affecting all levels of ecological trophic organization on the islands. The best way to deal with these problems is a holistic approach to restoration and recovery that benefits many taxa. Agency scientists (NPS, USGS, USFWS) drafted a conservation strategy for the islands (Coonan et al. 1999) that directs restoration efforts at higher trophic levels and across broad habitat types for ecosystem recovery. The removal of feral animals from several islands (see fig. 1) has been an enormous contribution moving the islands in the direction of recovery. The positive effects are demonstrated in trends seen in some of the monitoring data and in the population responses of individual native species. To this point, however, habitat-based restoration and recovery has been largely a passive effort, under the assumption that feral animal eradication has and will jump-start the system in the direction of recovery. The next step will be to begin habitat-based recovery efforts, now that the animals are gone, targeted at the restoration of native scrub and woodland cover used by many plants and animals. This effort must be a multifaceted approach, involving an aggressive noxious weed eradication campaign, landscape-level treatments that encourage the spread of natives, and managed reintroduction of sensitive natives like the island paintbrush and the island fox.

Literature cited

Beatty, S., and D. Licari. 1992. Invasion of fennel (*Foeniculum vulgare* Mill.) into shrub communities on Santa Cruz Island, California. Madrono 39:54–66.

Carroll, M. C., B. D. Reed, L. Laughrin, and D. Peart. 2003. Factors affecting seedling recruitment of woody species in oak woodland on Santa Cruz Island. Page 18 in D. K. Garcelon, editor. Sixth California Islands Symposium. The Institute for Wildlife Studies, Arcata, California.

Clark, R. A. 1989. The ecological status and distribution of the endangered succulent, Dudleya traskiae, on Santa Barbara Island, California. M.A. thesis. University of California, Santa Barbara, California.

Coonan, T., S. Chaney, K. Faulkner, L. Johnson, K. McEachern, C. Rutherford, C. Schwemm, and T. Thomas. 1999. A conservation strategy for the northern Channel Islands, California, USA. Channel Islands National Park, Ventura, California.

Coonan, T. J. 2001. Draft recovery plan for island foxes *(Urocyon littoralis)* on the northern Channel Islands. National Park Service, Ventura, California.

Corry, P. M., and K. McEachern. 2000. Native shrub recovery in nonnative annual grasslands, California Channel Islands. Pages 182–183 in D. R. Browne, editor. Proceedings of the Fifth California Islands Symposium. Minerals Management Service, Pacific OCS Region, Camarillo, California.

Hamer, T. E., and H. R. Carter. 2002. Population monitoring of Xantus's murrelets *(Synthliboramphus hypoleucus)* at Anacapa Island, California: 2001 annual report. Unpublished report prepared for the American Trader Trustee Council. Hamer Environmental L. P., Mt. Vernon, Washington; and Humboldt State University, Department of Wildlife, Arcata, California.

Hunt, G. L., Jr., R. L. Pitman, and H. L. Jones. 1980. Distribution and abundance of seabirds breeding on the California Channel Islands. Pages 443–459 in D. M. Power, editor. The California Islands: Proceedings of a Multidisciplinary Symposium. Santa Barbara Museum of Natural History, Santa Barbara, California.

Ingraham, N. L., and R. A. Matthews. 1995. The importance of fog-drip to vegetation: Point Reyes Peninsula, California. Journal of Hydrology 164:269–285.

Johnson, L., and D. Rodriguez. 2001. Terrestrial vegetation monitoring, Channel Islands National Park 1996–2000 annual report. Technical Report 01-06. Channel Islands National Park, Ventura, California.

Junak, S., T. Ayers, R. Scott, D. Wilken, and D. Young. 1995. A flora of Santa Cruz Island. Santa Barbara Botanic Garden, Santa Barbara, California.

Junak, S., S. Chaney, R. Philbrick, R. Clark. 1997. A checklist of vascular plants of Channel Islands National Park. Southwest Parks and Monument Association, Tucson, Arizona.

Levine, J., M. Rees, and K. McEachern. 2002. Environmental variation, dormancy, and rare plant persistence in invaded habitats. Proposal No. 092530369 to National Science Foundation. University of California, Santa Barbara, California.

Livingston, D. S. 2003. Historic resource study, Channel Islands National Park, draft 2. Draft Technical Report to Channel Islands National Park, Ventura, California.

Loeher, L. 2003. Santa Cruz Island chaparral community recovery. Page 82 in D. K. Garcelon, editor. Sixth California Islands Symposium. The Institute for Wildlife Studies, Arcata, California.

Lombardo, C. A., and K. R. Faulkner. 1999. The eradication of pigs *(Sus scrofa)* from Santa Rosa Island, Channel Islands National Park, California. Pages 300–306 in D. R. Browne, editor. Proceedings of the Fifth California Islands Symposium. Minerals Management Service, Pacific OCS Region, Camarillo, California.

McChesney, G. J., F. Gress, H. Carter, and D. L. Whitworth. 2000. Nesting habitat assessment for Xantus's murrelets and other crevice-nesting seabirds at Anacapa Island, California, in 1997. Unpublished report. U. S. Geological Survey, Western Ecological Research Center, Dixon, California; and Humboldt State University, Department of Wildlife, Arcata, California.

McEachern, K., and K. Chess. 2000. Soft-leaved paintbrush *(Castilleja mollis)* demography on Santa Rosa Island, California. Pages 158–160 in D. R. Browne, editor. Proceedings of the Fifth California Islands Symposium. Minerals Management Service, Pacific OCS Region, Camarillo, California.

McEachern, K., K. Chess, and J. Christian. 2003. Habitat fragmentation as a limiting factor in the recovery of soft-leaved paintbrush *(Castilleja mollis)*, Santa Rosa Island, California. (abstract). Page 153 in D. K. Garcelon, editor. Sixth California Islands Symposium. The Institute for Wildlife Studies, Arcata, California.

McEachern, K., S. Chaney and R. Clark. 2003. Field survey of Santa Barbara Island live-forever *(Dudleya traskiae)* numbers on Santa Barbara Island, Channel Islands National Park. Unpublished data, USGS-BRD Channel Islands Field Stations and Channel Islands National Park, Ventura, California.

Roemer, G. W., T. J. Coonan, D. K. Garcelon, J. Bascompte, and L. Laughrin. 2001. Feral pigs facilitate hyperpredation by golden eagles and indirectly cause the decline of the island fox. Animal Conservation 4:301–318.

Salas, D. E. 1990. The population dynamics of *Coreopsis gigantea* on Santa Barbara Island, Channel Islands National Park. M.S. thesis. Northern Arizona University, Flagstaff, Arizona.

Stratton, L. C. 2003. Santa Catalina Island experimental restoration trials: converting agricultural fields to native plant communities. Page 153 in D. K. Garcelon, editor. Sixth California Islands Symposium. The Institute for Wildlife Studies, Arcata, California.

Sumner, E. L., Jr. 1958. The rabbits of Santa Barbara Island—A progress report and summary. Unpublished report. Channel Islands National Park, Ventura, California.

Whitworth, D. L., H. R. Carter, R. J. Young, S. Fangman, and F. Gress. 2003. Status of the Xantus's murrelet at Anacapa Island, California, prior to and after the eradication of black rats. Page D. K. Garcelon, editor. Sixth California Islands Symposium. The Institute for Wildlife Studies, Arcata, California.

About the author

Kathryn McEachern, Ph. D., is a plant ecologist with the USGS–BRD Western Ecological Research Center, Channel Islands Field Station, in Ventura, California. She can be reached at 805-658-5753 and by email at kathryn_mceachern@usgs.gov.

"Role of Fire and Fire Management" continued from page 36

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23: 63–87.

D'Antonio, C. M., T. L. Dudley, and M. Mack. 1999. Disturbance and biological invasions: direct effects and feedbacks. Pages 413–452 in L. R. Walker, editor. Ecosystems of disturbed ground. Elsevier, New York, New York.

Glickman, D., and B. Babbitt. 1995. Federal wildland fire management policy and program review. Available from http://www.fs.fed.us/land/wdfirex.htm (accessed 30 July 2004).

Keeley, J. E. 2001. Fire and invasive species in California ecosystems. Pages 81–94 in K. E. Galley and T. P. Wilson, editors. Proceedings of the invasive species workshop: The role of fire in the control and spread of invasive species. Miscellaneous Publication No. 11. Tall Timbers Research Station, Tallahassee, Florida.

National Fire Plan. 2001a. Managing the impact of wildfires on communities and the environment. Available from http://www.fireplan.gov (accessed 30 July 2004).

National Fire Plan. 2001b. Ten-year comprehensive strategy: A collaborative approach for reducing wildland fire risks to communities and the environment. Available from http://www.fireplan.gov/reports/7-19-en.pdf (accessed 17 August, 2004).

National Fire Plan. 2002. FY 2002 Performance Report. Available from http://www.fireplan.gov/reports/1-1-en.pdf (accessed 17 August 2004).

National Park Service. 1996. A strategic plan for managing invasive nonnative plants on National Park System lands. USDI National Park Service, Washington, D.C. Available from http://www.nature.nps.gov/biology/invasivespecies/strat_pl.htm (accessed 30 July 2004).

National Park Service. 2003. Director's order and reference manual #18: wildland fire management http://www.nps.gov/fire/fire/fir_wil_planningandpolicy.html (accessed 30 July 2004).

Parsons, D. A., and T. J. Stohlgren. 1989. Effects of varying fire regimes on annual grasslands in the southern Sierra Nevada of California. Madrono 36:154–168.

Rejmanek, M. 1989. Invasibility of plant communities. Pages 369–387 in J. A. Drake, H. A. Mooney, F. di Castri, R. H. Groves, F. J. Kruger, M. Rejmanek, and M. Williamson, editors. Biological invasions: a global perspective. Wiley and Sons, New York, New York.

Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. Pages 4–10 in E. D. McArthur, E. M. Romney, S. D. Smith, and P. T. Tueller (editors). Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. General Technical Report INT-276. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, Utah.

About the authors

The authors are with the U.S. Geological Survey, Biological Resources Division, Sequoia and Kings Canyon Research Station, HCR 89, Box 4, Three Rivers, CA 93271; (559) 565-4266. The lead author can be contacted by email at kmerriam@usgs.gov.

Hemlock woolly adelgid **and the disintegration of eastern hemlock ecosystems**

By Richard A. Evans

An alien insect is causing decline in eastern hemlock forests, leading to the loss of native biodiversity, and opening the way for invasions of alien plants

Hemlock woolly adelgid *(Adelges tsugae)* is an aphid-like insect native to Asia that feeds exclusively on hemlock (*Tsuga* spp.) trees. First documented in Richmond, Virginia, in 1951, hemlock woolly adelgid (HWA) now occurs in 13 states, from Georgia to New Hampshire. During the past decade, HWA has been associated with widespread, severe decline and mortality of eastern hemlock *(T. canadensis)* trees. The insect also debilitates Carolina hemlock *(T. caroliniana)*, the other hemlock species native to the eastern United States. The geographic range of Carolina hemlock is limited to the southernmost Appalachian Mountains, which has just recently been infested by HWA. Examples of National Park System areas affected by HWA include Great Smoky Mountains and Shenandoah National Parks, New River Gorge National River, Catoctin Mountain Park, and Delaware Water Gap National Recreation Area.

Eastern hemlock is an ecologically important and influential conifer that for thousands of years was a major component of forests over much of the eastern United States. It is an extremely shade-tolerant species, and with appropriate climatic and site conditions forms nearly pure stands that can persist for hundreds of years. Hemlock-dominated forests create characteristically dark, acidic soil conditions that control and limit fundamental ecosystem characteristics such as plant and animal species composition, productivity, nutrient cycling, decomposition, and succession dynamics. During the past 400 years, the distribution and abundance of eastern hemlock was dramatically reduced by land clearing and logging, especially for the tanning industry, which utilized the tannic acid contained in the bark.

The decline and loss of our remaining eastern hemlock stands could be more ecologically significant in some respects than the loss of American chestnut *(Castanea dentata)* in the early 1900s because of chestnut blight. Following the demise of American chestnut, an array of native oak and hickory species naturally expanded, and have functioned as "ecological surrogates" for chestnut, providing habitat and mast (fruits and nuts) critical to many species of wildlife. In contrast, the species most likely to expand in declining hemlock stands include deciduous trees, white pine *(Pinus strobus)*, and invasive alien plants like "tree-of-heaven" *(Ailanthus altissima)*, Japanese barberry *(Berberis thunbergii)*, and Japanese stiltgrass *(Microstegium vimineum)* (Orwig and Foster 1996, Battles et al. 1999). These species will not provide habitat or ecological functions resembling those of eastern hemlock (fig. 1).

Figure 1. Openings in the canopy of hemlock forests killed by hemlock woolly adelgid at Delaware Water Gap National Recreation Area mean lost habitat for songbirds and other native wildlife. The disturbance also increases light and temperature in the forest understory, opening the way for invasive alien plants like Japanese barberry, Japanese stiltgrass, and "tree-of-heaven." NPS PHOTO BY RICHARD A. EVANS

HWA and hemlock forests at Delaware Water Gap

Eastern hemlock forests contribute much to the ecological, aesthetic, and recreational values of Delaware Water Gap National Recreation Area (Pennsylvania and New Jersey). Eastern hemlock is an important component of the forest canopy of 141 forest stands covering approximately 2,800 acres (1,134 ha) (about 5%) of the recreation area (Myers and Irish 1981, Young et al. 2002).

Many of these hemlock stands were designated in the recreation area's general management plan as "outstanding natural features" having "high intrinsic or unique values" (National Park Service 1987). Scenic waterfalls are associated with hemlock stands in the recreation area, and very popular activities like hiking, trout fishing, bird watching, and picnicking are concentrated in these areas.

Many of these hemlock stands were designated in the recreation area's general management plan as "outstanding natural features" having "high intrinsic or unique values."

Hemlock woolly adelgid was first detected within the national recreation area in 1989. In the fall of 1992, recreation area staff initiated a program to address the threat that HWA posed to valued park resources (Evans 1995, Evans et al. 1996). Three main goals of this program have been to (1) generate information about the distribution and abundance of HWA and hemlock tree health in the recreation area; (2) identify and document the distinctive characteristics of hemlock ecosystems in the recreation area, especially their contribution to park biodiversity; and (3) manage HWA and maintain hemlock ecosystems to the extent possible.

Monitoring

To monitor and relate HWA infestation levels to the health of individual hemlock trees, we established a system of 81 permanent hemlock plots at seven areas around the recreation area. Each plot includes 10 hemlock trees (810 trees total) permanently marked with individually numbered tags, so we can track the HWA populations and the health of each tree over the years. We have found a very strong relationship between HWA infestation level and the amount of new twig growth on branches (Evans 1996). As the HWA infestation level increases, the amount of new growth decreases sharply; branches having 45% or more of their twigs infested with HWA are unlikely to produce much new growth (fig. 2).

Ecological studies

We have used two complementary approaches to generate information about hemlock ecosystems and biodiversity in the recreation area. One approach has been to conduct detailed, "intensive" ecological studies at two sites (Battles et al 1999, Sciascia and Pehek 1995, Schrot 1998). The other approach has been to conduct less detailed, "extensive" studies at many sites, and compare hemlock forests to hardwood forests. In 1996, the Biological Resources Division (BRD) of the U.S. Geological Survey used a digital elevation model and data on park forest cover types and streams in a geographic information system to select 14 representative hemlock stands in the recreation area, and pair each of these hemlock stands with a hardwood stand having similar terrain characteristics (Young et al. 2002). Since then, studies of tree species composition (Sullivan et al. 1998), stream water temperatures and macroinvertebrates (Snyder et al. 2002), fish (Ross et al. 2003), salamanders (Brotherton et al. 2001), and forest breeding birds (Ross 2000) have been conducted at these 14 paired sites. Following are highlights from some of these studies at the paired hemlock and hardwood sites.

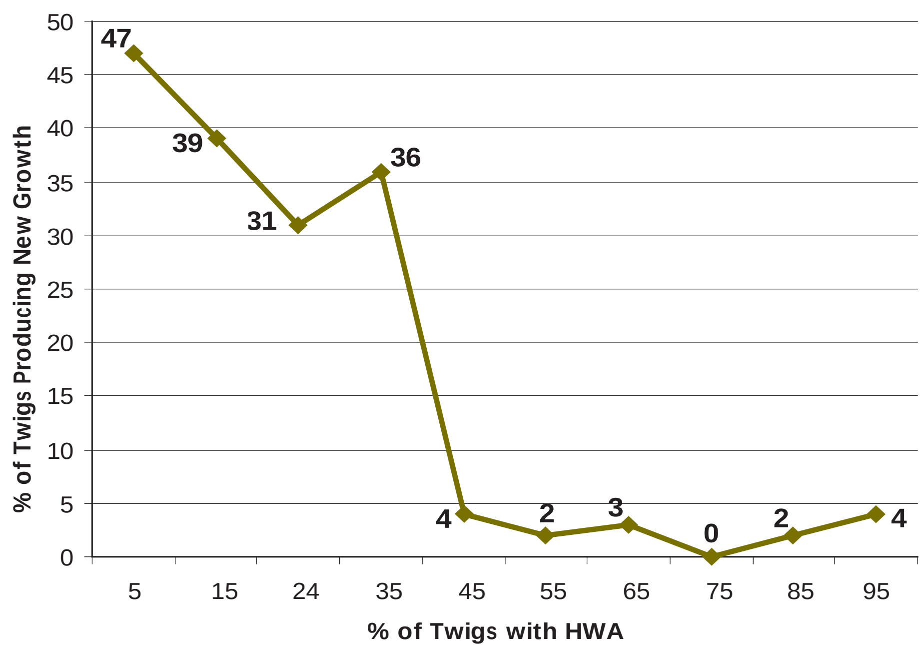


Figure 2. Relationship of HWA infestation level and new twig growth on hemlock branches at Delaware Water Gap National Recreation Area during summer 2000. Branches with 45% or more twigs infested with HWA produced almost no new growth. A total of 318 branches and 16,154 twigs were evaluated.

Results highlights

Small streams in hemlock forests support more macroinvertebrate species than similar small streams in hardwood forests in the recreation area. The average number of aquatic macroinvertebrate taxa found in hemlock streams was 37% greater than that found in hardwood streams (55 versus 40 taxa). Fifteen macroinvertebrate taxa were strongly associated with hemlock streams, and three taxa were found only in hemlock streams. No macroinvertebrate taxa were strongly associated with the hardwood streams (Snyder et al. 2002). Brook trout *(Salvelinus fontinalis)* are three times more likely to occur in small hemlock streams than in similar hardwood streams (Ross et al. 2003) in the recreation area.

Data from electronic temperature recorders showed that hemlock streams were consistently cooler in summer (May through September), and warmer in winter (December through February), than their paired hardwood streams in the recreation area. During June, July, and August, median daily temperatures in hemlock streams were typically 1° C to 2° C (1.8° F to 3.6° F) cooler than their hardwood stream counterparts. These stream temperature differences are potentially important to brook trout condition and survival. Temperatures above 20° C (68° F) are very stressful for brook trout. Whereas the maximum daily temperature in hemlock streams exceeded 20° C only 3% of the time, the maximum daily temperature in hardwood streams exceeded 20° C 18% of the time (Snyder et al. 2002).

Small streams draining hardwood forests are much more likely to dry up during summer droughts than similar small streams draining hemlock forests in the recreation area (table 1). The extent and frequency of stream channel drying is very likely a major factor controlling the aquatic macroinvertebrate assemblages, in addition to the occurrence of brook trout, in these small streams. The higher species richness in hemlock streams compared to hardwood streams is probably related to the frequency of hardwood streams drying up.

Table 1. Comparison of streams in hemlock and hardwood forests that dried up in summer 1997 and 1999

Forest Type	1997—% and (#)	1999—% and (#)
Hemlock	0 (0)	7 (1)
Hardwood	29 (4)	43 (6)
χ^2 p-value	0.013	0.023

Several species of breeding birds common in hemlock forests are rare or absent in hardwood forests in the recreation area (Ross 2000). These include the blackburnian warbler *(Dendroica fusca)*, black-throated green warbler *(Dendroica virens)*, and blue-headed vireo *(Vireo solitaris)*. Populations of these species will probably decline in the recreation area as hemlock forests decline. These conclusions are very similar to those drawn from studies in New Jersey (Benzinger 1994a and 1994b) and in the western Great Lakes region (Howe and Mossman 1995).

Hemlock forest management: maintain, mitigate, and restore

Biological control agents provide the only hope of limiting the damaging effects of HWA in large or remote hemlock forests. Several biocontrol agents for HWA are in the research and development phase (see papers in Onken et al. 2002). However, only one, the predatory "Pt" beetle *(Pseudoscymnus tsugae)*, has been available for use. Since completing an environmental assessment (Evans 2000) and a "Finding of No Significant Impact," we have released 65,000 Pt beetles in the recreation area (fig. 3).

Dead and dying hemlock trees in certain situations present threats to human safety and property that must be addressed. At Delaware Water Gap National Recreation Area, more than 250 dead or dying hemlock trees were cut down at a popular visitor use area in October 2002 (fig. 4).

Figure 3. Former national recreation area superintendent Bill Laitner releases HWA biocontrol beetles ("Pt" beetles) in Delaware Water Gap National Recreation Area, June 2000. NPS PHOTO BY RICHARD A. EVANS

Figure 4. Dead and dying hemlock trees in certain situations present threats to human safety and property that must be addressed. At Delaware Water Gap National Recreation Area, more than 250 dead or dying hemlock trees were cut down at a popular visitor use area in October 2002. NPS PHOTO BY RICHARD A. EVANS

We are currently working to develop a hemlock management plan for the park. We intend to develop strategies and techniques to foster regeneration of native tree species, curtail invasions by alien plant species in affected areas, and minimize impacts to park visitors.

Acknowledgements

Beth Johnson, Wayne Millington, and John Karish deserve special thanks for initiating and supporting the hemlock woolly adelgid program at Delaware Water Gap National Recreation Area. Many thanks also to Roger Rector, Bill Laitner, and Patrick Lynch for continuing support of this program. Thanks also to the many assistants, cooperators, and researchers who have worked on various aspects of this issue at Delaware Water Gap National Recreation Area during the past 10 years.

References

Battles, J. J., N. Cleavitt, T. J. Fahey, and R. A. Evans. 1999. Vegetation composition and structure in two hemlock stands threatened by hemlock woolly adelgid. Pages 55–61 in K. A. McManus, K. S. Shields, and D. R. Souto, editors. Proceedings of the Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America. USDA Forest Service GTR-NE-267. Durham, New Hampshire.

Benzinger, J. 1994a. Hemlock decline and breeding birds I: Hemlock ecology. Records of New Jersey Birds 20(1):1–12.

Benzinger, J. 1994b Hemlock decline and breeding birds II: Effects of habitat change. Records of New Jersey Birds 20(2): 34–51.

Brotherton, D., R. M. Bonett, J. L. Behler, and R. Cook. 2001. Paired hemlock-hardwood stream salamander survey, Delaware Water Gap National Recreation Area. Draft final report. National Park Service, Philadelphia, Pennsylvania.

Evans, R. A. 1995. Hemlock ravines at Delaware Water Gap National Recreation Area: highly valued, distinctive, and threatened ecosystems. Proceedings of the 35th Anniversary of Delaware Water Gap National Recreation Area. National Park Service, Milford, Pennsylvania.

Evans, R. A., E. Johnson, J. Shreiner, A. Ambler, J. Battles, N. Cleavitt, T. Fayhey, J. Sciascia, and E. Pehek. 1996. Potential impacts of hemlock woolly adelgid on eastern hemlock ecosystems. Proceedings of the First Hemlock Woolly Adelgid Review. FHTET 96—10:42–57. USDA Forest Service, Roanoke, Virginia.

Evans, R. 1996. Revised protocols for new growth and HWA data. Unpublished protocol guidelines. Delaware Water Gap National Recreation Area. National Park Service, Bushkill, Pennsylvania.

Evans, R. A. 2000. Environmental assessment for the release and establishment of *Pseudoscymnus tsugae* (Coleoptera: Coccinellidae) as a biological control agent for hemlock woolly adelgid *(Adelges tsugae)* at Delaware Water Gap National Recreation Area. National Park Service, Bushkill, Pennsylvania.

Howe, R. W., and M. Mossman. 1995. The significance of hemlock for breeding birds in the western Great Lakes region. Pages 125–139 in G. Mroz and J. Martin, editors. Proceedings of a conference on the ecology and management of eastern hemlock, 27–28 September 1995, Iron Mountain, Michigan. Department of Forestry, University of Wisconsin, Madison.

Myers, W. L., and R. R. Irish. 1981. Vegetation survey of Delaware Water Gap National Recreation Area. Final report. USDI National Park Service, Philadelphia, Pennsylvania.

National Park Service. 1987. General Management Plan for Delaware Water Gap National Recreation Area. Bushkill, Pennsylvania.

Onken, B., R. Reardon, and J. Lashomb. 2002. Proceedings: Hemlock Woolly Adelgid in the Eastern United States Symposium, 5–7 February 2002, East Brunswick, New Jersey.

Orwig, D. A., and D. R. Foster. 1996. Forest ecosystem response to hemlock wooly adelgid outbreak in southern New England. Bulletin of the Ecological Society of America 77:365.

Ross, R. 2000. Mesohabitat use of threatened hemlock forests by breeding birds at Delaware Water Gap National Recreation Area. Hemlock Woolly Adelgid Newsletter, Issue #5, USDA Forest Service. Available at http://www.fs.fed.us/na/morgantown/fhp/hwa/news5/hwa5.htm (accessed 8 July 2004).

Ross, R. M., R. M. Bennett, C. D. Snyder, J. A. Young, D. R. Smith, and D. P. Lemarie. 2003. Influence of eastern hemlock *(Tsuga canadensis)* on fish community structure and function in headwater streams of the Delaware River basin. Ecology of Freshwater Fish 12:60–65.

Schrot, A. 1998. Assessment of arthropod diversity associated with eastern hemlock forests at Delaware Water Gap National Recreation Area. Pennsylvania State University, University Park, Pennsylvania.

Sciascia, J. C., and E. Pehek. 1995. Small mammal and amphibian populations and their microhabitat preferences within selected hemlock ecosystems in the Delaware Water Gap National Recreation Area. Report to the National Park Service. New Jersey Department of Fish and Wildlife, Nongame Division; Trenton, New Jersey.

Snyder, C., J. Young, D. Lemarie, and D. Smith. 2002. Influence of eastern hemlock *(Tsuga canadensis)* forests on aquatic invertebrate assemblages in headwater streams. Canadian Journal of Fisheries and Aquatic Sciences 59(2):262–275.

Sullivan, K., B. Black, C. Mahan, M. Abrams, K. C. Kim, and R. Yahner. 1998. Overstory tree composition of paired hemlock and hardwood forest stands at Delaware Water Gap National Recreation Area. Final report. National Park Service, Philadelphia, Pennsylvania.

Young, J., C. Snyder, D. Smith, and D. Lemarie. 2002. A terrain-based, paired-site sampling design to assess biodiversity losses from eastern hemlock decline. Environmental Monitoring and Assessment 76:167–183.

About the author

Richard Evans is an ecologist at Delaware Water Gap National Recreation Area. He can be reached at richard_evans@nps.gov.

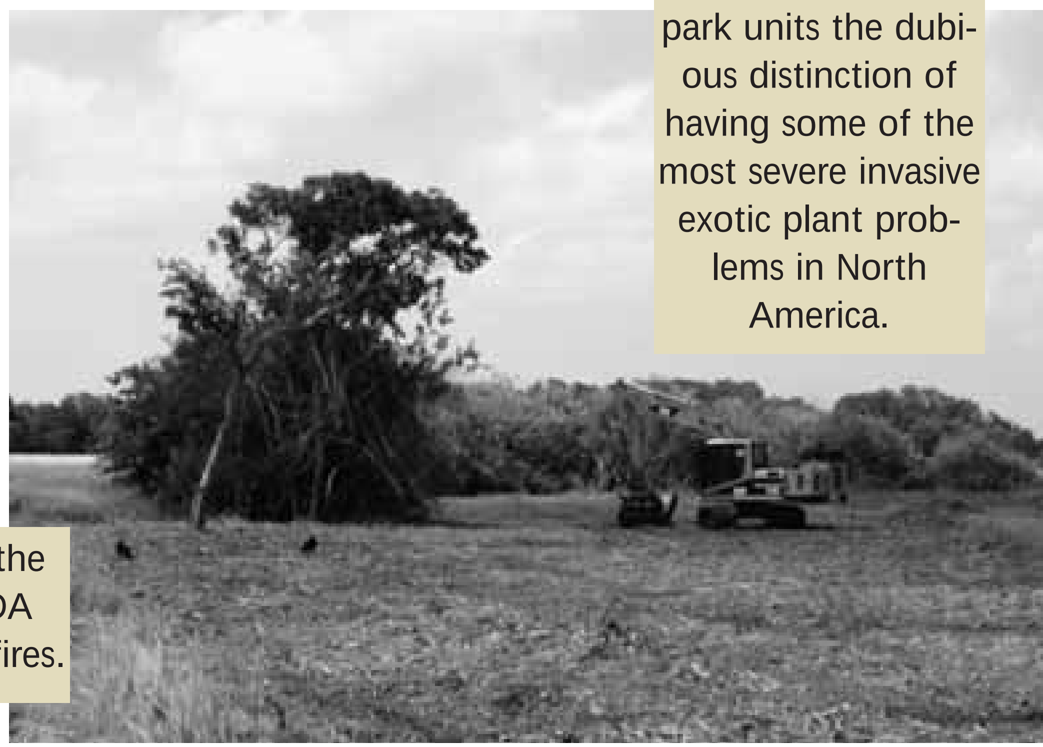
The Florida/Caribbean Exotic Plant Management Team Partnership

By Tony Pernas, Dan Clark, and Chris Furqueron

In 2000 the National Park Service established Exotic Plant Management Teams (EPMTs) through the Natural Resource Challenge to control invasive exotic plants on federal conservation lands. These EPMTs are modeled after the "strike teams" used by the USDA Forest Service to fight forest wildfires. Each highly trained, mobile strike force of plant management specialists stands ready to assist the national parks in the control of invasive exotic plants. Today 16 teams serve many units of the National Park System in the continental United States, Alaska, Hawaii, and the Virgin Islands.

Florida and lands in the Caribbean Sea are particularly prone to exotic plant invasions because of year-round growing conditions, natural and human-caused habitat disturbances, and the sheer number of species that have been introduced either for ornamental and agricultural purposes or unintentionally. In Florida, exotics infest more than 1.5 million acres (607,500 ha) of the state's natural areas and have spread rapidly to dominate native plant communities, minimize biological diversity, disrupt natural processes such as fire regimes and water flow, and change the landscape both visually and ecologically. More than 400,000 of approximately 2 million acres (162,000 of

More than 400,000 of approximately 2 million acres … of NPS lands in Florida and the Caribbean are infested with exotic pest plants, thus giving these park units the dubious distinction of having some of the most severe invasive exotic plant problems in North America.



These EPMTs are modeled after the "strike teams" used by the USDA Forest Service to fight forest wildfires.

810,000 ha) of NPS lands in Florida and the Caribbean are infested with exotic pest plants, thus giving these park units the dubious distinction of having some of the most severe invasive exotic plant problems in North America.

The Upland Invasive Plant Management Program of the Florida Department of Environmental Protection (DEP) was established in 1997 to curb the spread of exotic pest plants on public conservation lands. Through this program, the state partners, with more than 400 public land managers, work together to control exotic plants. Regional working groups select the projects and on-the-ground control efforts are made by private contractors through service contracts.

In 2000 the Department of Environmental Protection and the National Park Service entered into a partnership to establish the Florida EPMT (FLEPMT). Under this partnership the National Park Service selects and submits projects to the department. Costs for the projects are shared and control is accomplished using private contractors, reducing expenses and increasing efficiency.

In 2003 the FLEPMT expanded to include the U.S. Virgin Islands. This expansion was the result of a cooperative agreement with the University of Florida under a grant from the USDA Subtropical Agricultural Research Program. The name of the team was changed to Florida/Caribbean Partnership EPMT (FLCEPMT).

More protection, less process

The FLCEPMT has completed its fourth year. Since its establishment the team has inventoried and mapped more than 8 million acres (3,240,000 ha) for invasive plants and provided for the initial treatment of invasive plants on 15,281 acres (6,189 ha). Funding for inventory has been from the South Florida Water Management District, U.S. Department of Agriculture, Agricultural Research Service, and Loxahatchee National Wildlife Refuge. Funding for control has been from the National Park Service (Natural Resource Challenge) and is matched by the Florida Department of Environmental Protection. In FY 2000–FY 2003 the National Park Service contributed $1.528 million, while the Florida Department of Environmental Protection provided $1.33 million, and the Cooperative Conservation Initiative of the U.S. Department of the Interior funded $540,000. All of these projects have been successful at controlling invasive plants and have also been very cost-effective. Through the use of private contractors, the cost per acre for control projects has been approximately $225 ($91/ha).

The team has undertaken invasive plant control projects at Big Cypress National Preserve; Biscayne, Everglades, Dry Tortugas, and Virgin Islands National Parks; Buck Island Reef and Fort Matanzas National Monuments; Canaveral and Gulf Islands National Seashores; and DeSoto National Memorial. On four of these units (Desoto, Dry Tortugas, Gulf Islands, and Fort Matanzas), initial treatment of the most invasive plant species has been completed. Significant strides have been made in the other parks receiving funding.

In addition to the success in treating invasive plants, the greatest achievements have been in public education and in developing partnerships with surrounding landowners, such as demonstrated by the following projects:

- The FLCEPMT has entered into a cooperative agreement with the South Florida Water Management District for mapping exotic plants on 8 million acres of natural areas in south Florida.

- In Canaveral National Seashore, an interagency exotic plant control program is in progress. Participating agencies include Volusia County and Merritt Island National Wildlife Refuge.

- In Biscayne National Park, staff working with adjacent landowners assisted in establishing a memorandum of agreement with Miami-Dade County, South Florida Water Management District, and The Nature Conservancy. This agreement, administered by the NPS Southeast Regional Office, works toward achieving maintenance control of exotic plants for the entire south Biscayne Bay ecosystem.

- The FLCEPMT is currently initiating international partnerships to share technical information and conduct joint control projects in the Caribbean.

The Florida/Caribbean Partnership EPMT is involved with more than 400 federal, state, regional, and local cooperators and is broadening its participation to include others. The continued success of EPMTs relies upon building public and private partnerships to efficiently prevent, control, and manage damaging exotic species now and for the future. Exotic weeds recognize no boundaries and cooperative efforts are critical to addressing invasive species control and protecting public natural areas.

More information can be found at the NPS EPMT Web site: http://www.nature.nps.gov/epmt.

Tony Pernas is exotic plant management specialist on the Florida/Caribbean Exotic Plant Management Team, Big Cypress National Preserve, Florida. He can be reached at tony_pernas@nps.gov.

Dan Clark is exotic plant management specialist at Virgin Islands National Park, U.S. Virgin Islands; daniel_clark@nps.gov.

Chris Furqueron is integrated pest management specialist at the Southeast Regional Office in Atlanta,Georgia; chris_furqueron@nps.gov.

Impacts of West Nile virus on wildlife

MOSQUITO PHOTOS COPYRIGHT JOHN VAN DYK

By Emi Kate Saito and Margaret A. Wild

In 1999, investigators discovered dead crows and human cases of encephalitis in New York City to be associated with West Nile virus. This discovery marked the first time that the virus—a mosquito-borne pathogen native to Africa, the Middle East, Asia, and Europe—had been detected in the western hemisphere. How the virus came to the United States remains unknown. Many believe that the virus was introduced through importation of an infected mosquito, bird, human, or other animal; however, others believe introduction occurred when infected birds were blown off course during migration.

From 1999 through 2003, the virus spread along the East Coast and into the Midwest. By the end of 2003 the virus had been detected in 46 states and the District of Columbia, and 7 Canadian provinces (i.e., Manitoba, Nova Scotia, Ontario, Quebec, Alberta, New Brunswick, and Saskatchewan). In addition, evidence of West Nile virus circulation has been detected throughout Mexico and several Caribbean islands. Birds are the natural host for West Nile virus, although humans, horses, and other animals can become ill from the disease. Indeed, West Nile virus has become a serious human health concern with outbreaks in 2003 responsible for the deaths of 262 people in the United States alone, 61 of which occurred in Colorado, the most for any particular state.* Unlike previous epidemics in other countries where horses and humans primarily were affected, the U.S. epidemic has been associated with high levels of avian mortality, particularly in corvids (e.g., crows, jays, magpies, and ravens). Since 1999, investigators have detected the virus in more than 225 bird and 20 mammal species, and even captive alligators. To date, most surveillance programs have focused primarily on corvids and raptors; therefore, the list of affected species undoubtedly will continue to expand as more species are tested.

*The Centers for Disease Control and Prevention maintains a Web site at http://www. cdc.gov/ncidod/ dvbid/westnile/index.htm on West Nile virus that includes information on ways to reduce the human health risks of the disease.

Many surveillance programs also have tested mosquitoes to assess virus activity. Currently, investigators have found the virus in 47 mosquito species. However, at present, scientists still do not know which of these species are the most important in virus transmission or maintenance of the disease in nature. Utilizing the bird and mosquito information of their area in an effort to decrease human risk, many public health agencies have been able to plan prevention and control strategies more efficiently based on local environmental and ecological characteristics.

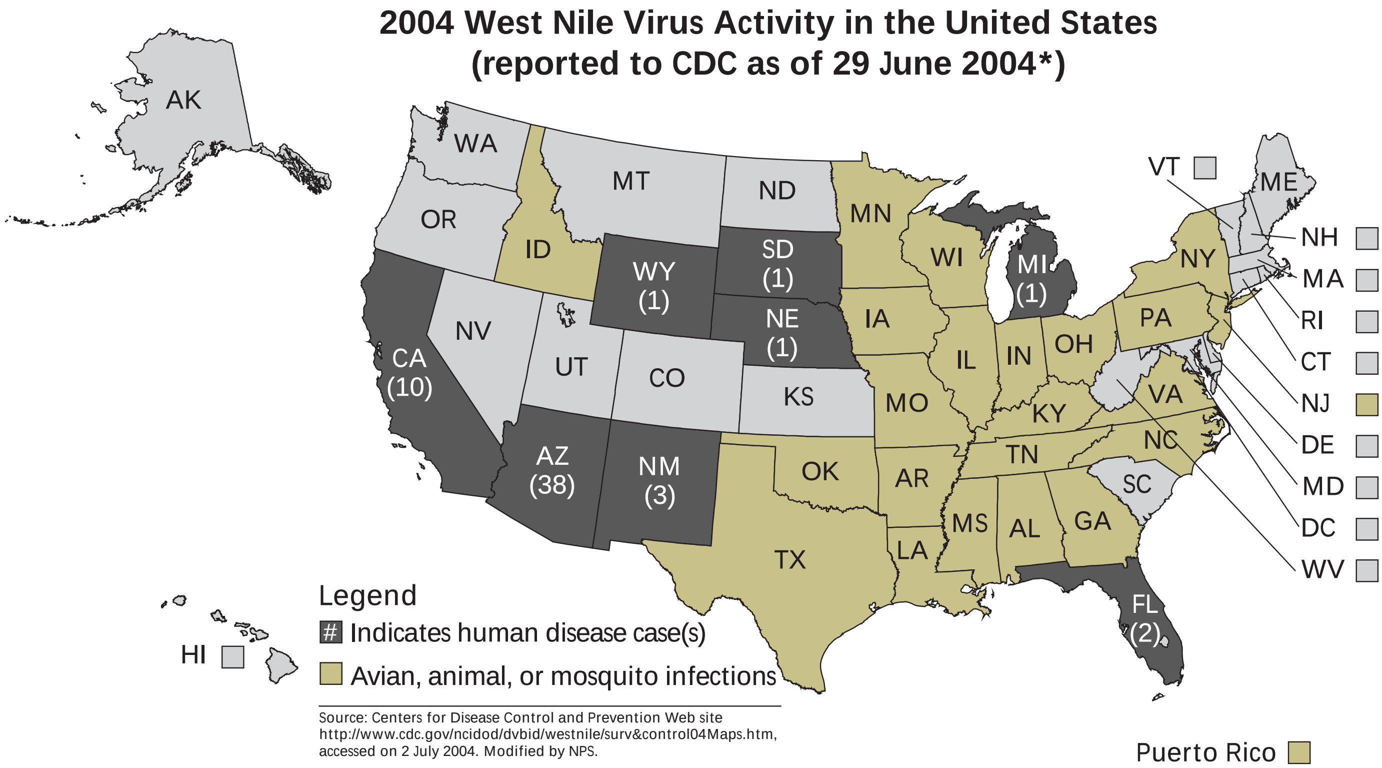
In units of the National Park System, integrated pest management techniques guide surveillance and mosquito control efforts. Cooperation and coordination between NPS resource managers, public health risk management experts, and local authorities assure that control efforts protect public health, while taking into consideration NPS management policies and impacts on natural resources. Many units in the National Park System have active programs that include surveillance of dead birds, mosquito testing, and education, prevention, and sanitation activities.

A significant question for resource managers regarding the epidemic is: What is the impact of West Nile virus on wildlife populations? Since 2001, more than 325,000 dead birds—with no visible effects attributed to predation or other causes of death—were reported to public health and wildlife agencies. Because a large number of dead birds are never found, these reports represent only a fraction of the number of dead birds in the wild. Some reports estimate the number of birds that potentially died of West Nile virus to annually exceed 1 million.

A significant question for resource managers regarding the epidemic is: What is the impact of West Nile virus on wildlife populations?

Since 2001, more than 87,000 dead birds were tested for the virus, with at least 36,000 testing positive (CDC ArboNet contributors, unpublished data). However, because birds tested for West Nile virus were not evaluated for other causes of death, the role of the virus as a source of mortality has not been determined.

Some anecdotal reports suggest localized declines in bird populations, but efforts to evaluate the impact of



Source: Centers for Disease Control and Prevention Web site http://www.cdc.gov/ncidod/dvbid/westnile/surv&control04Maps.htm, accessed on 2 July 2004. Modified by NPS.

*West Nile virus maps are updated by the CDC regularly to reflect surveillance reports released by state and local health departments to the CDC Arbonet system for public distribution.

The map shows the distribution of avian, animal, or mosquito infection occurring during 2004 with number of human cases, if any, by state. If West Nile virus infection is reported to CDC Arbonet in any area of a state, that entire state is shaded accordingly.

West Nile virus are ongoing. As occurrences of the disease increase in the western United States the number of species, including threatened and endangered species, potentially at risk increases substantially. With limited management options, some zoos have vaccinated rare birds with the licensed equine vaccine (Fort Dodge West Nile Virus Innovator) following the recommended protocols for equine vaccination. However, the efficacy of this vaccine is unknown, and no vaccines have yet been approved for use in birds. New vaccines are under development and some developed for human and equine use have been tested, but none have been reported to be efficacious in bird species.

The recent epidemic of West Nile virus in the United States proved to be unexpectedly active and was the largest epidemic of the virus ever recorded.

The recent epidemic of West Nile virus in the United States proved to be unexpectedly active and was the largest epidemic of the virus ever recorded. Much remains to be discovered about the ecology and epidemiology of West Nile virus in the United States, including which species are important in maintaining the virus in nature, why some species are more susceptible to lethal infection, and what environmental factors are important in predicting future epidemics. These factors will likely vary regionally, depending on local ecological characteristics. Until scientists better understand the virus and factors influencing its activity, predicting its effects for future seasons is impossible. However, experts are certain about one thing: West Nile virus is here to stay.

About the authors

Emi Kate Saito is the West Nile virus surveillance coordinator for the USGS National Wildlife Health Center in Madison, Wisconsin. She can be reached at 608-270-2456 or esaito@usgs.gov.

Margaret A. Wild is a wildlife veterinarian for the NPS Biological Resource Management Division in Fort Collins, Colorado. She can be reached at 970-225-3593 or margaret_wild@nps.gov.

Understanding relationships among invasive species and soils

By Pete Biggam

Soil plays a key role in many biological and physical processes. It is involved in nutrient cycling, the hydrologic cycle, and energy capture and transfer. It serves as the rooting material for most terrestrial vascular plants, and provides essential habitat for numerous ground-dwelling species. Unfortunately, past and present impacts from a wide variety of invasive plant and animal species threaten the ability of park soils to function properly. By increasing our understanding of the physical, chemical, and biological properties of soil, we may be able to do a better job of controlling the distribution and extent of invasive species.

Salt cedar … has the ability to absorb salts from the subsoil and store them in its leaves. As these leaves are shed … salt leaches back into the topsoil, increasing salinity and further reducing the ability of native plants to compete with this invader.

Ironically, invasive plant species have been used in the past in an effort to protect valuable soil resources. In the 1930s, the USDA Soil Conservation Service promoted the planting of kudzu *(Pueraria Montana* var. *lobata)* for controlling accelerated soil erosion in the southeastern United States, and Russian olive *(Elaeagnus angustifolia)* was also highly recommended as a windbreak to reduce erosion in the Midwest and western United States. However, invasive plants can damage soil and water resources through the displacement of native plant species. This in turn affects the type and amount of soil litter available to minimize surface runoff and water and wind erosion.Today, we have a better understanding of the relationships among invasive plant species and soils. Studies have shown that numerous invasive plant species have an affinity for certain physical and chemical properties of soil, and may outcompete native species on these sites if the soils are disturbed. Diffuse knapweed *(Centaurea diffusa)*, Russian knapweed *(C. repens)*, and spotted knapweed *(C. maculosa)* tend to do well on drier sites with coarse-textured, well-drained soils with elevated levels of calcium carbonate. Medusahead *(Taeniatherum caput-medusae)* is well suited to establishment on soils that are high in clay. Yellow star-thistle *(Centaurea solstitialis)* can outcompete native and other invasive plant species on shallow, rocky soils. Salt cedar (*tamarix* spp.) can establish itself on highly saline soils along riparian corridors and can tolerate highly alkaline conditions. It has the ability to absorb salts from the subsoil and store them in its leaves. As these leaves are shed and deposited on the soil surface, salt leaches back into the topsoil, increasing salinity and further reducing the ability of native plants to compete with this invader.

Studies have shown that numerous invasive plant species have an affinity for certain physical and chemical properties of soil, and may outcompete native species on these sites if the soils are disturbed.

Figure 1. Northern temperate forests are being invaded by exotic earthworms that rapidly consume the organic matter in the soil. USGS PHOTO

In park units in arid and semiarid ecosystems, biological soil crusts are a dominant feature and play a valuable role in stabilizing soils. Disturbance of the soil surface and introduction of invasive plants can result in loss of biological crust cover, which in turn can reduce soil stability and alter nutrient cycles, soil moisture, and temperature regimes, affecting the soil food webs.

At Dinosaur National Monument, Colorado, the relationships among soils and invasive plants are being addressed in the Cub Creek weed management and restoration planning project. Resource managers have determined that infestations of Russian knapweed tend to be limited to the coarser textured soils, and have yet to encroach upon the soils of predominantly clay textures. Staff plan on using the recently completed soil survey for the monument to help identify other potential areas susceptible to establishment of Russian knapweed, as well as identifying areas that may be less susceptible for establishment, based upon soil textural properties identified in the soil survey.

Resource managers have traditionally focused on the impacts of invasive plants on soils; however, invasive animal species also threaten this resource. The wild hog *(Sus scrofa)*, common in many units of the National Park System, is notorious for extensive disturbance of soil and vegetation communities as a result of its rooting habits when foraging. Lacking sweat glands, the hogs search out poorly drained soils and create wallows where they cool off and rid themselves of parasites. Wallowing compacts the soil and destroys its structure, opening up new areas for invasive plants to colonize. Recent studies have also warned of the invasion of northern temperate forests by exotic earthworms (fig. 1). These seemingly innocuous animals have the potential to greatly alter ecosystem processes by rapidly consuming the organic matter in the soil, depriving native plants of beneficial places to germinate and grow (see Information Crossfile, pages 9 and 31, for more information). The result is a seemingly bare forest floor that invites invasion by exotic plant species (fig. 2).

The NPS Soils Inventory and Monitoring Program is working to obtain soil resource inventories for approximately 275 national park units. These inventories will contain additional information on the relationships among specific invasive plants, animals, and soil types that will help us gain insights into the ways in which invasive plants and animals affect our valuable soil resources.

Pete Biggam is Soils Inventory and Monitoring Program coordinator, Natural Resources Information Division, Lakewood, Colorado, and can be contacted at pete_biggam@nps.gov.

Figure 2. The result of the earthworms is a bare forest floor that invites invasion by exotic plant species.
USGS PHOTO

INVASIVE SPECIES: a biological wildfire

By Tom Stohlgren

Resource managers throughout the country are quick to realize that the ecological, economic, and human-health costs associated with invasions of nonnative species may be as catastrophic as wildfire. Lightning-like strikes have occurred, for example, in Haleakala National Park (Hawaii) in the form of avian malaria and Argentine ants, as Brazilian peppertree throughout the Everglades and kudzu in the South, a storm of tamarisk throughout southwestern parks and monuments, a lake trout from the Great Lakes in Yellowstone Lake, and a brown tree snake in Guam. Moreover, flame-like spread of Dutch elm disease, chestnut blight, white pine blister rust, and sudden oak death has devastated forests throughout the United States. Despite continuous new threats like West Nile Virus and the snakehead fish, however, a coordinated effort to battle invasive species has not occurred. Where is the "National Interagency Fire Center" for biological wildfires when we need it?

The ... Fort Collins Science Center ... emphasizes invasive species as one of the top eight USGS research focus areas and one of the top environmental threats of the 21st century.

The U.S. Geological Survey (USGS) is spearheading the development of such an interagency center. The USGS National Institute of Invasive Species Science at the Fort Collins Science Center is an interagency consortium with nongovernmental partnerships that directly addresses invasive species issues on public and adjacent lands. To predict and reduce the harmful effects of nonnative plants, animals, and diseases in natural areas throughout the United States, the U.S. Geological Survey established the institute to develop a comprehensive plan for stomping out invasive species, to provide national leadership, and to disseminate and synthesize up-to-date, accurate data and research from many sources. The institute applies a strategic approach to information management, prevention, early detection, research and modeling, technical assistance, and outreach. The newly built Fort Collins Science Center, Colorado, where the institute is based, coincided with organizational restructuring that emphasizes invasive species as one of the top eight USGS research focus areas and one of the top environmental threats of the 21st century.

Where is the "National Interagency Fire Center" for biological wildfires when we need it?

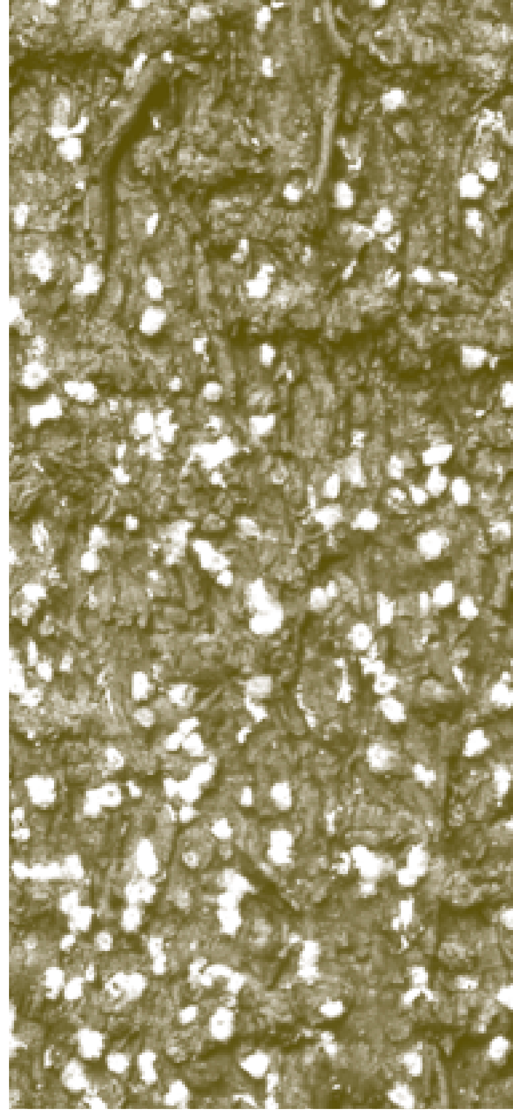
Staffs at the institute began by collecting and synthesizing national databases on nonnative plants, nonindigenous fishes, birds, and wildlife diseases (table 1), including a systematic evaluation of the nation's 530 or so wildlife refuges via electronic questionnaires sponsored by the U.S. Fish and Wildlife Service. Another important aspect of the program is to improve predictive models of invasions (or "ecological forecasting" models) with the help of sponsored research by NASA Goddard Space Flight Center. We are developing predictive models for Rocky Mountain National Park (Colorado), the Grand Staircase–Escalante National Monument (Utah), and the Cerro Grande Fire area near Bandelier National Monument (New Mexico). Other efforts include mapping the highest priority invasive weeds throughout Colorado in partnership with the state, Colorado State University's Agricultural Experiment Station, and county weed coordinators.

Table 1. National databases for invasive species

Group of Invasive Species	Primary Investigator	Program
Nonnative plants	John Kartesz	Biota of North America Project
Nonindigenous fishes	Pam Fuller	USGS South Florida and Caribbean Science Center
Birds	John Sauer	Patuxent Wildlife Research Center
Birds	Bruce Peterjohn	USGS Bird Conservation Node of the National Biological Information Infrastructure
Wildlife diseases	Josh Dein	USGS National Wildlife Health Center

See "Biological Wildfire" in right column on page 70

The health of our forests and what we are doing about it



By Terry Cacek

The health of forests in the National Park System is not good. The reasons are many, and they vary from east to west. Although problems with western forests have received the most publicity, the most critical problems may be in the East.

A suite of foreign diseases and insects has assaulted the eastern forests (figs. 1–3). The chestnut, once the dominant tree species in many areas of the East, is ecologically extinct, as is the American elm. Both were taken by imported diseases. Oak, hemlock, dogwood, ash, maple, beech, and butternut are being diminished by exotic diseases and insects.

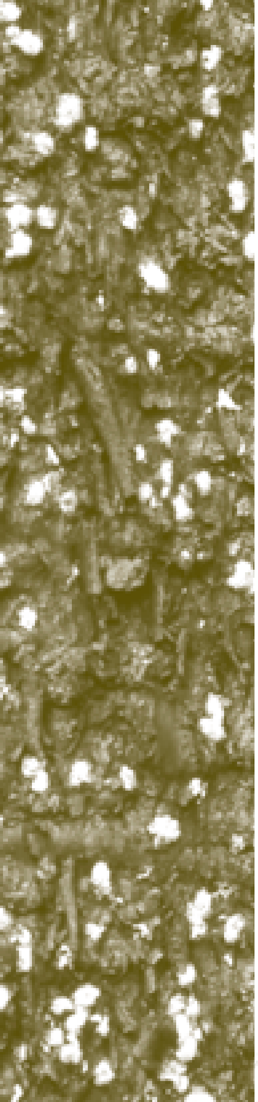
Oak, hemlock, dogwood, ash, maple, beech, and butternut are being diminished by exotic diseases and insects.

For decades, the major management response by the National Park Service in eastern forests has been protecting oaks from attack by the European gypsy moth. Stands are monitored annually, and when egg mass counts exceed threshold levels, the stands are treated with target-specific insecticides.

Western forests suffer primarily from excessive tree density, the result of decades of over-protection from natural wildfire. Now, close spacing makes trees vulnerable to catastrophic, unnatural wildfires. The trees compete with each other for space, light, water, and nutrients. This crowding combines with stresses associated with air pollution, long-term climate change, and recent droughts to weaken the trees and make them vulnerable to native insects. Under these conditions, bark beetles and other insects kill some trees and move tree density back toward a pristine, healthy condition. Therefore, parks generally manage native insects only in campgrounds and other developed areas.

However, exotic organisms are also threatening western forests. The Port Orford cedar of the Pacific Northwest is being decimated by a root disease. Hikers spread it on the soles of their boots. The staff at Redwood National Park (California) is trying to contain the disease by rerouting a trail around an infected area so that it will be avoided by hikers.

Sudden oak death is a deadly fungus that is no longer confined to oaks, having been confirmed recently in redwood, Douglas fir, and dozens of other species. It spread rapidly along the Pacific Coast but was contained by the barriers of deserts and high mountains. Nevertheless, in 2004 it was detected in nursery stock shipped from California to eastern nurseries. Foresters have scrambled to impose quarantines in the hope of preventing its escape to the wild in the East.



Programmatic action

Two programs in the National Park Service deal with forest health. The larger is the Fire Program, which controls catastrophic wildfires and is assuming a role in reducing tree densities of western forests. Its many activities are beyond the scope of this article. The Forest Health Program assumes the task of protecting forests from immediate attacks by insects and diseases. The program employs the full array of integrated pest management methods, ranging from spraying insecticides to sanitation (i.e., removal of infected trees). Sometimes, the objective is simply to control the rate of spread of an insect or disease. For example, Muir Woods National Monument, northwest of San Francisco, is a hotspot for sudden oak death. Hikers leaving the park are required to walk across a pad soaked with disinfectant to kill the fungus on their boots and prevent its spread to other stands of trees.

The Forest Health Program is supported entirely by monies from the USDA Forest Service, which funds technical assistance of a highly professional, nationwide staff of forest entomologists and pathologists. The National Park Service typically forwards 12 to 15 proposals to the Forest Service annually, with total funding requests in the range of one-third to one-half million dollars. In most years, about 90% of the proposals are funded.

Forests for the future

What should ultimately be the goal of these interventions to aid forests in the National Park System? Incessant threats, both alien and domestic, are causing biologists to rethink a desirable vision of forest health, what forest conditions are possible to achieve, and what trade-offs we may be forced to make. Some believe we can return our forests to their original condition. In some western forests, that vision may be biologically possible by reducing tree densities, but costs and logistics are major, perhaps insurmountable, impediments. In the East, so many species have been lost that the pre-Columbian condition will never be restored.

In the East, so many species have been lost that the pre-Columbian condition will never be restored.

Other biologists have a more pragmatic vision. The larger landscape in which forests survive has been irrevocably altered. The remaining besieged forest is fragmented by roads and other development, and overbrowsing by deer is hindering regeneration. Perhaps the best we can do is assess ecological history, current conditions, and the biological feasibility of restoration, and try to achieve a future forest that is functional and comprises the remaining vigorous native species.

Figure 1 (top left). Balsam woolly adelgid, a nonnative insect, has killed more than 80% of mature Fraser fir trees in Great Smoky Mountains National Park (Tennessee and North Carolina). The park contains 74% of all Fraser fir in the southern Appalachian Mountains.

Figure 2 (top right). Native to central Europe, the tiny adelgid feeds on the stem and large branches where it disrupts nutrient flow, potentially killing Fraser firs in less than five years. Nationally and globally rare bryophytes that live on the bark of Fraser fir also are threatened by the drier conditions that occur when firs die.

Figure 3 (left). In limited areas, resource managers at Great Smoky Mountains National Park spray balsam woolly adelgids with insecticidal soap to keep a remnant fir population alive.
NPS Photos

Terry Cacek, Ph. D., is an integrated pest management coordinator with the Biological Resource Management Division in Fort Collins, Colorado. He can be reached at terry_cacek@nps.gov.

Zebra mussels threaten native mussels of the St. Croix National Scenic Riverway

Figure 1. If they attach to native mussels in enough numbers, nonnative zebra mussels interfere with normal filter-feeding, movement, reproduction, and eventually respiration of the native species.

By Randy S. Ferrin

When the St. Croix National Scenic Riverway, Minnesota and Wisconsin, was established in 1968 as one of the original eight components of the National Wild and Scenic River System, the Wild and Scenic Rivers Act never mentioned the incredible diversity of life found under the river's surface. Notably, nothing was said about the 40 species of freshwater mussels found there. We now know the St. Croix River's mussel assemblage is one of the most robust in the Upper Midwest, if not North America. These relatively long-lived animals, some of which typically can live for several decades, are a reflection of their environment, a true vital sign of the ecosystem's health. Yet even in the St. Croix River they are threatened by changes in water quality, loss of habitat because of sedimentation, and loss of fish host species. Two species are listed federally as endangered, and 15 others are state-listed by Minnesota or Wisconsin. The welfare of the mussel community is of great concern to the National Park Service, the U.S. Fish and Wildlife Service, and our state and tribal partners.

In addition to its other threats, these animals face a new threat from an exotic invader from Eurasia, the zebra mussel (*Dreissena polymorpha*, fig. 1). Zebra mussels came to North America via ballast water in freighters traveling into the Great Lakes. Unlike native mussels, zebra mussels do not need a fish host to aid their early development. Instead, the female zebra mussel spews up to 30,000 eggs into the water column and a nearby male fertilizes the eggs with a cloud of sperm. The fertilized eggs remain in suspension and develop into free-floating microscopic veligers, which can drift in the water column for approximately 17 days. As the veliger develops, it produces a sticky, thread-like mass, the byssal thread, which allows it to stick to any hard substrate it collides with, including the hulls of boats and barges. It can also settle onto the river bottom where it likewise attaches to any hard substrate, such as the shell of a native mussel.

With the ability to float freely as veligers, or travel on the hulls of boats as juveniles or adults, zebra mussels have been able to gain considerable territory in a very short time. From the Great Lakes, zebra mussels traveled down the Illinois River to the Mississippi. Going upstream is not possible for the veligers, but by attaching to the hulls of commercial and recreational vessels juveniles and adults are carried upstream where they can remain on the boat or drop off to attach to another hard substrate. If zebra mussels attach to native mussels in enough numbers, they interfere with normal filter-feeding, movement, reproduction, and eventually respiration of the native species. Zebra mussels literally smother native mussels in this manner. Even when present in nonfatal densities, zebra mussels compete for the same food source as the natives.

By attaching to the hulls of ... vessels juveniles and adults are carried upstream where they can remain on the boat or drop off to attach to another hard substrate.

Sections of the Mississippi River support zebra mussels in densities of a meter (3.6 ft) deep, with tens of thousands per square meter (10.8 sq ft), killing all of the native mussels in those locations. Boats that harbor or travel in the Mississippi are highly likely to be contaminated with zebra mussels. Of great concern to riverway managers is the free travel allowed between the Mississippi and the St. Croix Rivers. The States of Minnesota and Wisconsin administer the lower 25 miles (40.2 km) of the riverway, while the National Park Service has jurisdiction from there to the headwaters of the unit. The states do not have the authority within their section to close the river to boats coming from the Mississippi. Since 1994, boats that harbor at marinas in the St. Croix River have been documented with zebra mussels attached, and the number has gone up every year since then. Finally, as feared, juvenile zebra mussels were found on substrates in the St. Croix River during monitoring dives in 2000. Luckily, the infestation has been limited to the lower 20 miles (32 km) of the riverway. Unfortunately, this stretch contains critical habitat for one of the federally listed species, the Higgins-eye pearly mussel (*Lampsilis higginsi*, fig. 2).

Of great concern to riverway managers is the free travel allowed between the Mississippi and the St. Croix Rivers.

Not willing to allow this to happen in the NPS-administered section, the National Park Service established a point on the river beyond which upstream travel is prohibited (fig. 3). Boats from upstream can pass downstream of the checkpoint but are not allowed to travel back. This closure got further impetus in 2001 from a biological opinion issued by the U.S. Fish and Wildlife Service related to the Environmental Impact Statement for the Lower Riverway Cooperative Management Plan (the general management plan for the lower riverway).

The zebra mussel prevention program has been very costly to the National Park Service and our partners but it serves as the final chance for the preservation of the river's native mussels. In addition to the closure, the Park Service has developed a combination passive-active monitoring program. Passive monitoring involves a network of Hester-Dendy-type plate samplers, while active involves periodic inspection dives by our interagency dive team (fig. 4). We also conduct random inspections on boats that are transported by trailer to upstream landings. Finally, educational efforts are a large component of our prevention program (fig. 5). Our strategy has remained that preventing the invasion is the best approach because we cannot turn back once zebra mussels have become established. This is a high-stakes battle and losing the riverway's incredible diversity of native mussels is not an acceptable outcome.

Randy S. Ferrin is chief, Natural Resources Division, St. Croix National Scenic Riverway. He can be reached by e-mail at randy_ferrin@nps.gov.

NPS PHOTOS/ILLUSTRATION

Figure 2 (top photo). Although the spread of zebra mussels in the St. Croix National Scenic Riverway has been limited to the lower 20 miles of the unit, this stretch contains critical habitat for one of the federally listed native mussel species, the Higgins-eye pearly mussel.

Figure 3 (middle photo). In an effort to prevent the spread of zebra mussels into the park, the National Park Service prohibits upstream boat travel beyond a specific point on the St. Croix River.

Figure 4 (bottom photo). An interagency dive team conducts periodic monitoring of the St. Croix National Scenic Riverway to learn the status of the zebra mussel in the park and inform management action.

Figure 5 (illustration). The zebra mussel prevention program at the St. Croix Riverway includes a public education component.

Salamanders and introduced fish in mountain lakes of two Pacific Northwest parks

By Gary Larson and Robert Hoffman

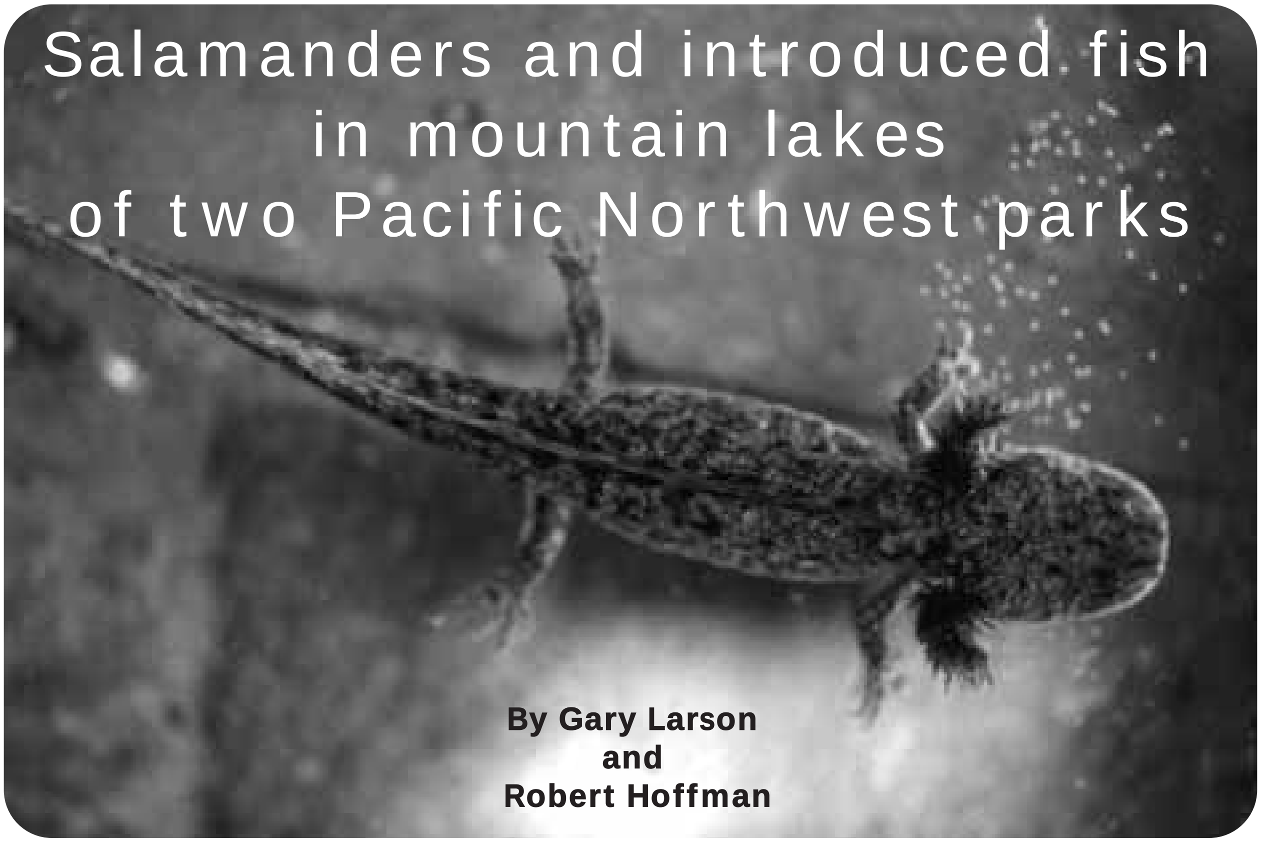


Figure 1. Typical larval form of the northwestern salamander.
ROBERT L. HOFFMAN

During the last century, many fishless mountain lakes in the Pacific Northwest were stocked with nonnative fish, such as brook trout, for recreational purposes. The introduced fish replaced native salamander larvae as the top aquatic vertebrate predator in these lakes. To understand the impact of the fish on the salamanders, we investigated the abundance of larvae in mountain lakes where nonnative fish had been introduced. At Mount Rainier National Park and North Cascades National Park Service Complex (which includes Ross Lake and Lake Chelan National Recreation Areas, in addition to North Cascades National Park), we surveyed previously fishless lakes that had been stocked, and lakes without fish. (For more information on survey methodology, see Hoffman et al. 2003. Habitat segregation of *Ambystoma gracile* and *Ambystoma macrodactylum* in mountain ponds and lakes, Mount Rainier National Park, Washington. Journal of Herpetology 37:24–34.) The studies suggest that two salamander species are affected quite differently by the introduction of fish because of differences in the distributions, life history characteristics, and habitat requirements of the two species.

The two salamander species studied were the long-toed salamander *(Ambystoma macrodactylum)* and the northwestern salamander (*Ambystoma gracile,* fig. 1). We found greater abundances of larvae of both species in fishless lakes (fig. 2). Also, we found that when fish are present in a lake, larvae of both species restrict their daytime activity to nearshore areas where much bottom cover (such as

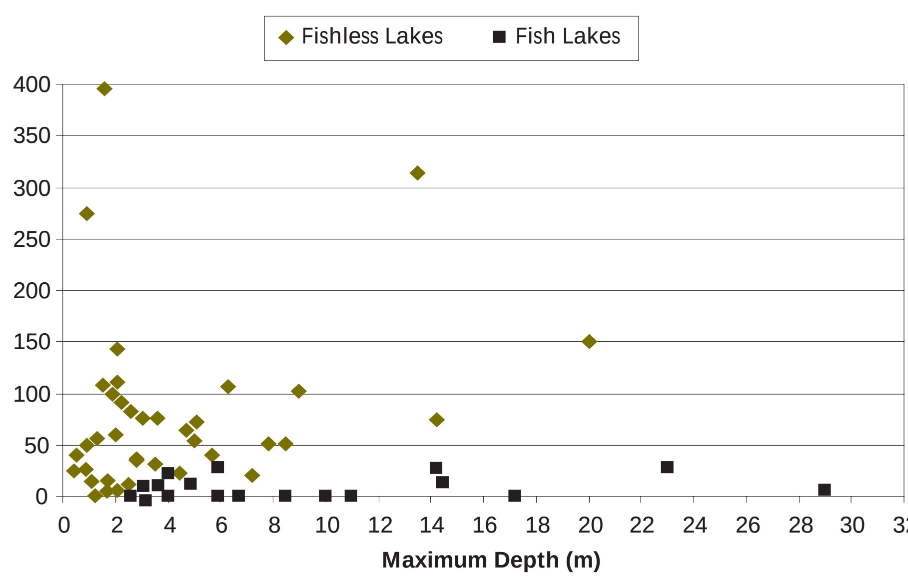


Figure 2. The number of salamander larvae observed per 100 m surveyed in Mount Rainier National Park ponds or lakes that have fish or are fishless. (Depths are maximums.)

To evaluate the finding that introduced fish affect salamander abundance and behavior, we removed fish from a small lake in Mount Rainier National Park that had a population of northwestern salamander larvae.

submerged logs and tree branches) is available, and they are primarily active at night. To evaluate the finding that introduced fish affect salamander abundance and behavior, we removed fish from a small lake in Mount Rainier National Park that had a population of northwestern salamander larvae. The fish were removed over a period of six years, with most removed within the first two years. Once fish were removed, the total number of larvae observed (fig. 3), and the proportion of larvae observed offshore compared to nearshore, increased during daytime surveys.

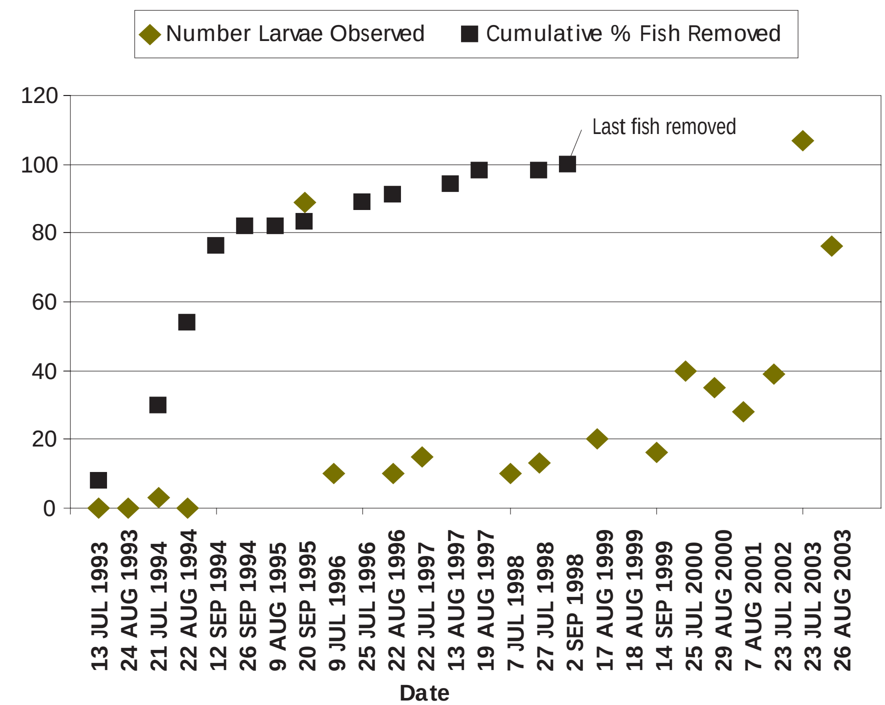


Figure 3. The number of salamander larvae observed per 150 m surveyed during daytime in Mount Rainier National Park increased from 1993 through 2003 when fish were removed from the lake.

Experiments conducted in artificial ponds to investigate trout predation on northwestern and long-toed salamander larvae have shown that both species suffer reduced abundance because of predation by trout. These results are borne out by examination of feeding habits of introduced fish in natural lakes. The two salamander species have different life-history characteristics, however, which is one factor that affects the way each species responds to the presence of fish. Northwestern salamanders in mountain lakes typically reach reproductive maturity without transforming into terrestrial adults. These individuals are known as neotenes or aquatic gilled-adults. Neotenes can grow to be more than 7 inches (175 mm) in total length, which is as large as many of the trout in the lakes, and they tend to be less vulnerable to predation by the trout. Since neotenes and smaller larvae cannot survive on land and are therefore restricted to the lakes they inhabit, individuals that coexist even at low abundance with introduced fish alter their behavior to reduce their interaction with the fish. In these lakes, northwestern salamanders are very secretive and remain hidden during the daytime when they are more vulnerable to predation by trout.

Long-toed salamanders do not have the aquatic gilled-adult life-stage and must transform into terrestrial adults. As terrestrial adults, they can leave lakes that have fish and limit their reproductive activity to fishless lakes and small shallow ponds if these sites are located relatively close to the lakes from which they emerge. If fishless lakes and ponds are not available, terrestrial adults will continue to reproduce where fish are present and may be eliminated from these lakes. Although terrestrial adults can grow to more than 6 inches (150 mm) in total length, larvae are much smaller at the time of metamorphosis (1.75-in or 48-mm snout–vent length) and are vulnerable to trout predation. Long-toed salamanders that are occasionally found at low abundance in lakes with fish are present only in the structurally complex shallow areas of the lakes where they can, like northwestern salamanders, more easily escape predation.

The two species also have different distributions and habitat requirements that affect their vulnerability to fish. Northwestern salamanders are primarily found in lakes greater than 7 feet (2.1 m) deep, that is, in lake basins that do not fill to the bottom with ice and snow in winter. Long-toed salamanders live in both deep and shallow lakes and ponds. Recent evidence suggests that when northwestern salamanders are present, they exclude the long-toed species from the deep lakes. Thus, the depth of the water and the interaction between salamander species determines which one is present and which will be impacted by the introduction of the fish.

At Mount Rainier National Park both species are present. The long-toed salamanders occupy lakes less than 7 feet (2.1 m) deep. Fish usually cannot survive in such shallow water; therefore, at this park, long-toed salamander larvae are rarely affected by introduced fish. The northwestern salamanders occupy the deeper lakes where fish are present and so are impacted by them.

At North Cascades National Park Service Complex, the distribution of northwestern salamanders is more limited than at Mount Rainier: No northwestern salamanders are found on the eastern side of the hydrologic divide of the Cascades Range, and relatively few populations occur west of the divide because this is the easternmost extent of their range. Thus, the long-toed salamander is able to inhabit both deep and shallow lakes and ponds east of the divide. West of the divide the same is true, except in the occasional deep lakes where northwestern salamanders occur. This widespread distribution means that the long-toed salamanders are more likely to be impacted by the introduced fish than the relatively uncommon northwestern salamanders.

This study underscores the importance of developing separate management strategies for each salamander species based on its life history characteristics, habitat requirements, and vulnerability to fish impact. Resource managers need to be aware of the distribution patterns of the salamanders and introduced fish in the parks, especially as the distributions relate to lake size, depth, and habitat. Since the National Park Service has ended the stocking of lakes with fish almost entirely, the fish in some stocked lakes have become extinct. However, fish still remain in lakes where they have achieved a level of reproductive success. These are the lakes that should be of concern to managers when developing strategies for the maintenance of native larval salamander populations, or strategies for the recovery and restoration of sensitive and threatened native salamander species. The removal of fish from lakes in areas where these species occur could be an important management objective. For managers on other montane lands who stock fish, knowing the distributions of native salamander species could influence which lakes are stocked. Understanding how introduced fish impact aquatic ecosystems and how larval salamanders and other amphibians are affected and respond to the presence of fish can help managers support and monitor the ecological integrity of these ecosystems.

This study underscores the importance of developing separate management strategies for each salamander species based on its life history characteristics, habitat requirements, and vulnerability to fish impact.

About the authors

Gary Larson is research manager, USGS Forest and Rangeland Ecosystem Science Center, Corvallis, Oregon. He can be reached at gary_l._larson@usgs.gov.

Robert Hoffman is a senior faculty research assistant in the Department of Fisheries and Wildlife at Oregon State University, Corvallis, Oregon. He can be reached at robert.hoffman@oregonstate.edu.

"Biological Wildfire" continued from page 63

To help manage the volume of information on nonnative species, we created the Invasive Species Information Node as part of the National Biological Information Infrastructure—a broad, collaborative program to provide increased access to data and information on the nation's biological resources (see http://www.nbii.gov/). When fully operational, the Invasive Species Information Node will:

- Evaluate the invasion of multiple biological groups (and several invasive species) simultaneously, relative to habitat and ecosystem maps, land-use maps, and "change detection" satellite information and models.
- Zoom in on particular states, parks, refuges, and natural areas by merging data sets from many sources into single, dynamic representations of the highest priority problem species and problem areas.
- Access invasive species information and models on local, state, regional, and national scales.
- Quickly assess vulnerability to invasion, current invasions, potential spread of species, natural barriers to invasion, and the economic and ecological effects of invasive species.

The node will increase accessibility of data, accelerate the sharing of information, and promote the use of predictive modeling in developing strategic, proactive approaches to invasive species containment and control. Specifically for the National Park Service, we will assist in evaluating local, regional, and national patterns of control efforts by the Exotic Plant Management Teams. By mapping the location of target species in relation to derived environmental data (e.g., slope, aspect, elevation, and community type), we will be able to quantify patterns of current invasion and probable distributions of priority species, as well as assess the vulnerability of habitat types to invasion. Immediately summarized data and models will help guide strategic control and restoration strategies.

The core aspect of our work is sharing data and information, which will improve predictive modeling. Sharing data and information promotes a proactive rather than reactive approach to the management of invasive species. The USGS National Institute of Invasive Species Science and National Biological Information Infrastructure are committed to the long-term delivery of unbiased, scientific data in support of resource management of public lands.

About the author

Tom Stohlgren is an ecologist with the USGS National Institute of Invasive Species Science at the Fort Collins Science Center in Fort Collins, Colorado. He can be reached at tom_stohlgren@usgs.gov or 970-491-1980. The institute's Web site is http://www.niiss.org.

Meetings of Interest*

November 3–5, 2004

The North American Lake Management Society (NALMS) conference—“Lakes: Habitat for Fish, Habitat for People”—addresses challenges associated with the coexistence of people and fish in lake habitats. This is one of the few conferences where academics, scientists, government employees, and ordinary citizens gather to address the problems that face the use of lakes in a global atmosphere of increasing population and climate change. During discussions, technical workshops, and training sessions held in Victoria, British Columbia, NALMS 2004 includes other topics such as introduced aquatic plants and animals, lake assessment and restoration techniques, government policies, and new scientific methods. More information is available at http://www.nalms.org/symposia/victoria/index.htm.

November 8–10, 2004

Third International Conference on Invasive *Spartina* provides a forum for the best and latest research on *Spartina* and an opportunity to hear from marsh managers and technical experts from around the world. Beautiful and important in their native ecosystems, several species of *Spartina* become ecological and economic nightmares when they establish at the interface between land and sea in nonnative territories. The conference includes scenic ground and helicopter tours to view and contemplate the *Spartina* “hybrid swarm” (*S. alterniflora* x *S. foliosa*) that threatens the San Francisco Estuary. The overarching theme for the conference held in downtown San Francisco, California, is “Integrating the Science and Management of Invasive *Spartina*.” More information is available at http://www.the-conference.com/2004/spartina/.

November 14–17, 2004

“Entomology and ESA: Our Heritage, Our Future” is the premiere event of the Entomological Society of America (ESA). Participants gather in Salt Lake City, Utah, to exchange scientific information and ideas, enhance professional knowledge and skills, and conduct ESA business. A formal program of events provides attendees with opportunities to hear and present research papers, and meet in symposia to discuss selected topics of common interest, including hemiptera-microbe interactions; the integration of ecology, pest management, epidemiology, and genomic research; mechanical properties of arthropod structures: engineering the future; the well “bee-ing” of pollinators and their impacts on agricultural and natural ecosystems; rhopalocera erotica: a passion for butterflies; and the malaria-fighting mosquito: challenges and progress in the most daring undertaking in 50 years of genetic vector control. More information is available at http://www.entsoc.org/annual_meeting/2004/ameeting.htm.

April 19–20, 2005

“Invasive Species: Their Ecological Impacts and Alternatives for Control” focuses on supporting the assessment and monitoring of invasive species. Specific topics include approaches for preventing the introduction and spread of invasive species; identification of standardizations that the American Society for Testing and Materials (ASTM) International, Committee-E47 on Biological Effects and Environmental Fate might develop to meet technical and regulatory challenges; and identification of invasive species research needs. Organized in 1898, ASTM International is one of the largest voluntary standards developing organizations in the world. Participants at the event in Reno, Nevada, come together under ASTM to set consensus standards for invasive species control. More information is available at http://www.astm.org/cgibin/SoftCart.exe/SYMPOSIA/index.html?L+mystore+cxpl5647+1092341496.

* Readers with access to the NPS Natural Resources Intranet can view a comprehensive listing of upcoming meetings, conferences, and training courses at <http://www1.nrintra.nps.gov/NRMeet/>.

PARKSCIENCE
National Park Service
WASO-NRID
P.O. Box 25287
Denver, CO 80225-0287

PARKSCIENCE
INTEGRATING RESEARCH AND RESOURCE MANAGEMENT

VOLUME 22 • NUMBER 2 • FALL 2004

www.nature.nps.gov/parksci

ISSN 0735–9462

PUBLISHED BY U.S. Department of the Interior
National Park Service

DIRECTOR Fran Mainella

ASSOCIATE DIRECTOR, NATURAL RESOURCE STEWARDSHIP & SCIENCE Michael Soukup

EDITOR Jeff Selleck

ASSISTANT EDITORS Betsie Blumberg, under cooperative agreement CA 4000-8-9028
Katie KellerLynn, under cooperative agreement CA 1200-99-0009

ADDITIONAL CONTRIBUTORS Nina Roberts

DESIGN Glenda Heronema—Denver Service Center

EDITORIAL OFFICE Jeff Selleck
National Park Service
P.O. Box 25287
Denver, CO 80225-0287
E-mail: jeff_selleck@nps.gov
Phone: 303-969-2147
FAX: 303-987-6704

Park Science is a resource management bulletin of the U.S. National Park Service that reports recent and ongoing natural and social science research, its implications for park planning and management, and its application to resource management. Published by the Natural Resource Information Division of the Natural Resource Program Center, it appears twice annually. Thematic issues, such as this one, that explore a topic in depth are published occasionally. Content is reviewed for usefulness, basic scientific soundness, clarity, completeness, and policy considerations, but does not undergo anonymous peer review.

Letters that address the scientific content or factual nature of an article are welcome; they may be edited for length, clarity, and tone.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service.

Articles, comments, address changes, and inquiries should be directed to the editor by email; hard copy materials should be forwarded to the editorial office.

Park Science is also published online (ISSN 1090-9966). All back issues, article submission guidelines, and other useful information can be accessed from www.nature.nps.gov/parksci.

Park Science accepts subscription donations from non-NPS readers to help defray production costs. A typical donation is $10 per subscription per year. Checks should be made payable to the National Park Service and sent to the editorial office address.

Sample article citation
Benjamin, P., and R. Hiebert. 2004. Assessing the invasive plant issue. Park Science 22(2):27–31.

Printed on recycled paper