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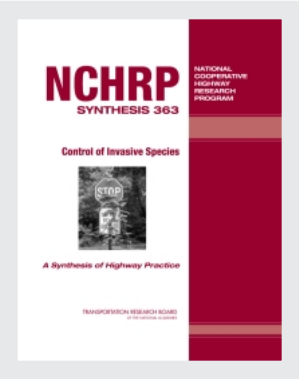

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 363

Control of Invasive Species

A Synthesis of Highway Practice

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Littleton, Colorado

SUBJECT AREAS
Energy and Environment and Bridges, Other Structures, and Hydraulics and Hydrology

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2006
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation
Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This synthesis will be of interest to state transportation agency personnel, as well as to others who work with them on vegetation management. Environmental pressures, coupled with recent federal directives have significantly increased the need for control of invasive species. This report explores the extent to which state departments of transportation are identifying actions that affect the spread of invasive species, preventing introduction, tracking status and locations of "invasives" in a timely and ongoing manner, controlling found populations, restoring invaded habitats, conducting research, and sharing lessons learned. Information is presented about federal, state, and regional approaches; prevention, early detection, and rapid responses; identification of aspects of operations and risks; and statewide inventories and information management. Successful practices are documented, as well as lessons learned. In particular, this report synthesizes the state of the practice in developing Integrated (Roadside) Vegetation Management, along with physical, chemical, biological, and cultural control mechanisms.

This synthesis effort contains information received from 40 state transportation agencies and the U.S. Forest Service, supplemented by material collected as part of a literature process. Personal interviews were also conducted to add details that show the issues facing practitioners today.

Marie Venner, Venner Consulting, Littleton, Colorado, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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CONTROL OF INVASIVE SPECIES

SUMMARY

Transportation agencies manage approximately 12 million acres of land in transportation rights-of-way. Vegetation management therefore is a primary activity of department of transportation (DOT) maintenance forces in all 50 states, Puerto Rico, and the District of Columbia, as well as for local highway departments across the country. Vegetation management can involve significant department staff and staff time, and the battle against invasive species and their effects on the aesthetic and natural environments is requiring increasing time and resources. Vegetation management affects transportation systems, public health, the economy, and natural environments. As transportation corridors for plant and animal invasives carried by traveling vehicles, highways cross geologic barriers that previously prevented the spread of species. Consequently, transportation corridors are a factor in the spread of and loss of natural habitat, the top two drivers of declining biodiversity. Increased species rarity has been a concern to other agency partners and stakeholders. These pressures and Executive Order 13112, which directs all federal agencies to address invasive species concerns and refrain from actions likely to increase invasive species problems, have made a synthesis of existing practice for controlling invasive species more urgent than ever before.

This synthesis reviews federal, state, and regional approaches; prevention, early detection, and rapid responses; identification of aspects of operations and risks; statewide inventories; and information management. In particular, this report synthesizes the state of the practice in developing Integrated (Roadside) Vegetation Management, along with physical, chemical, biological, and cultural control mechanisms. The synthesis also covers DOTs' organizational approaches, staffing, training, and partnerships for invasive species control, along with resources for transportation agencies. It reports on the extent to which DOTs are identifying actions that affect the spread of invasive species, preventing introduction, tracking status and locations of invasives in a timely and ongoing manner, controlling found populations, restoring invaded habitats, conducting research, and sharing lessons learned.

DOTs surveyed and interviewed for this study commented that Executive Order 13112 has helped increase awareness of and efforts to control invasive species. Transportation agencies have begun performing species surveys on construction projects; controlling infestations; and revegetating with native, lower maintenance species. Coordination among environmental, design and landscape architecture, and construction staff is on the upswing, addressing environmental impacts and eradication and control of invasive species before, during, and after construction.

DOTs are taking a variety of steps to share information across division areas and professional specialties, address cross-cutting needs, and take a more integrated approach to invasive species control. Information is often exchanged informally. Chief among the more formal approaches is the development of organization-wide and district-specific integrated vegetation management plans. Geographic information systems enable the locations of weed patches to be stored digitally, and allow treatments to be tracked, automatically administered in some cases, and assessed over time. Highly effective, lower tech communication mechanisms such as posters and laminated illustrations of various top priority weeds are common as well. DOT landscape architects and roadside managers have also

developed session topics at statewide annual environmental, construction, and maintenance meetings. Training of agency employees and contractors has been a notable key to success.

Inadequate funding is the primary obstacle faced by state DOTs and others trying to control invasive species. Control efforts tend to be highly fragmented. Statewide roadside inventories for invasive species have been undertaken by 20% of DOTs to assess what needs and challenges there are and the effectiveness of treatments over broader periods of time and space. However, many DOTs say that they are unlikely to attempt such inventories, with several reporting that they were impeded by lack of templates or guidance on invasive species management.

CHAPTER ONE

INTRODUCTION

BACKGROUND AND ROLE OF TRANSPORTATION IN SPREAD AND CONTROL OF INVASIVE SPECIES

The battle against invasive species and their impacts on the aesthetic and natural environments is requiring increasing time and resources from state departments of transportation (DOTs), other agencies, businesses, and individuals. Organisms that have been moved from their native habitat to a new location are typically referred to as "non-native," "non-indigenous," "exotic," or "alien" to the new environment. A small percentage of non-native organisms cause serious problems in their new environments and are collectively known as invasive species or "invasives."

Most food crops and domesticated animals in the United States are non-natives, but not invasive. Many other non-native species are simply benign. However, invasive species and their costs to society are increasing at an alarming rate, stimulated by the rapid global expansion of trade, transport, and travel. In some cases, having arrived over many years, invasive species can require a long-term commitment to control.

The means and routes by which invasive species are imported and introduced into new environments are called "pathways." Some invasive species arrive as hitchhikers on commodities such as nursery stock. Others are stowaways in transport equipment or packing materials (*1*). Transportation corridors provide opportunities for the movement of invasive species through the landscape. Highways cross geologic barriers that previously prevented the spread of species, serving as avenues to transport invasive plants and animals, as well as cars and people. The transport of weed seeds by vehicles and the spread of invasive species caused by substandard vegetation or revegetation are particularly well documented (*2*). An Australian study found that approximately half of all cars studied were carrying seeds (*3*). Consequently, transportation corridors are a factor in the spread of invasives and the loss of natural habitat, the top two drivers of declining biodiversity.

Where transportation corridors intersect waterways, these effects can rapidly spread to additional areas. Invasive plant or animal species can move on vehicles and in the loads they carry. Invasive plants can be moved from site to site during roadside maintenance operations. Weed seed can be inadvertently introduced into a corridor during construction on equipment and through the use of mulch, imported soil, water, or gravel and sod. Some invasive plant species may be deliberately planted as part of erosion control, landscape, and wildflower projects.

Although DOTs contend with and try to make headway against insects and other fauna, including fire ants and West Nile Virus, invasive plant challenges within vegetation control absorb most of the DOTs' attention, time, and resources. Vegetation management affects public health, our economies (especially agricultural), and natural environments. Top vegetation management issues for DOTs in terms of investment are:

- Managing vegetation along the road edge, in drainage ditches, and other unpaved areas.
- Managing vegetation around safety devices and signs.
- Managing erosion on slopes.
- Maintaining highway plantings and desired vegetation (and avoiding or reducing undesirable vegetation such as invasive species).
- Managing vegetation in paved areas, such as pavement cracks.
- Maintaining shoulder backing integrity.
- Maintaining environmental quality, including reducing invasive species and promoting native communities.

The scoping, planning, design, construction, operation, and maintenance of highways, facilities, and transportation corridors all play a key role in the management, or lack thereof, of invasive species. Over the last decade, and especially in the last few years, considerations for the spread and control of priority invasive species have been incorporated into the activities of many DOTs on an ad hoc basis. Some regional initiatives have incorporated a systematic regimen to set management priorities, and identify, inventory, and control priority invasive plant species. Currently, DOTs are beginning to develop policies, procedures, and practices to consider and address, to the extent practicable, the impacts of invasive species in all aspects of scoping, planning, design, construction, operation, and maintenance for all projects and activities.

The environmental stewardship commitments of state DOTs and Executive Order (E.O.) 13112, which directs all federal agencies to address invasive species concerns and refrain from actions likely to increase invasive species problems, have prompted transportation agencies to extend their work in controlling invasive species. The threats posed by

invasives and declining state budgets have made a synthesis of efficient and effective practices more urgent than ever before.

SCOPE AND OBJECTIVES

This synthesis focuses on the state of the practice of DOTs in managing invasive species and what has been learned by university researchers and managers of linear corridors, including the utility industry. In particular, this synthesis explores the extent to which DOTs are:

- Identifying actions that may affect the status of invasive species,
- Preventing the introduction of invasive species,
- Tracking status and locations of invasive species in a timely and ongoing manner,
- Controlling populations of invasive species,
- Restoring invaded habitats, and
- Conducting research and incorporating and sharing lessons learned.

METHODOLOGY

This synthesis was undertaken in cooperation with DOT roadside environmental managers, maintenance managers, environmental specialists, ecologists, agronomists, natural resources managers, and landscape architects across the country. Knowledge was gleaned from university utility integrated pest/vegetation management researchers as well. The synthesis reviews and summarizes the state of invasive species control practice, synthesizing and presenting further resources.

Central to the research effort was a survey of DOTs from the 50 states, the District of Columbia, and Puerto Rico. Responses were received from 40 states, a 75% response rate. Contributions were also received from the U.S. Forest Service. A list of respondents is provided in Appendix B.

ORGANIZATION

This introductory chapter presents the background of the problem, scope and objectives, and organization. Chapter two reviews the issue and definitions, federal and state policies and priorities, and state and regional methods for tackling invasive species control. Chapter three reviews prevention, early detection, and rapid response approaches; identifies aspects of operations and risks, statewide inventories, and information management; and provides a greater level of detail on planning for invasive species, including connecting inventories to plans and developing Integrated (Roadside) Vegetation Management (IRVM) plans. Chapter four details roadside invasive species control mechanisms, reviewing physical, chemical, biological, and cultural controls. The prevalence of DOT use of these methods, as discovered in the survey, is also included in this section, along with links to many DOT and other guides and resources for implementing the control methods discussed. Chapter five reviews DOTs' organizational approaches, staffing, training, and partnerships for invasive species control. Obstacles, lessons learned, public outreach, and streamlining approaches are discussed as well. Chapter six includes the estimated benefits of invasive species control, gaps, and opportunity areas for greater effectiveness in invasive species control and conclusions. The following appendices are provided to assist DOTs in locating assistance on-line and among their peers. The survey distributed to state DOTs (Appendix A); a list of responding agencies (Appendix B); sample New York State DOT invasive species inventory forms (Appendix C); an overview of common IRVM or Integrated Vegetation Management (IVM) steps including cost–benefit information regarding invasive species control (Appendix D); and state DOT research related to invasive species control (Appendix E). A glossary of relevant terms is also provided.

CHAPTER TWO

INVASIVE SPECIES—A GROWING PROBLEM

WHAT ARE INVASIVE SPECIES? STATE AND FEDERAL DEFINITIONS

For the purpose of this report, invasive plant species are defined as those found outside of their native range and, owing to certain characteristics, are able to move into an area and become dominant numerically, in cover, resource use, or other ecological impact.

E.O. 13112, "Invasive Species" defines invasive as "alien (non-native) species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (*4*). Invasive species can be plants, animals, and other organisms (e.g., microbes).

The large majority of non-native species—those occurring in locations beyond their known historical natural ranges and/or brought in from other continents, regions, ecosystems, or habitats—do not pose a threat to the natural or human systems in which they are introduced. However, a small percentage of non-native species that become established have the potential to become invasive and cause significant economic, environmental, and human health consequences (*5*). After introduction in a new environment, invasive species may establish easily and quickly, compete aggressively, and grow rapidly, presenting a threat to native species and habitats.

As transportation corridors enable people and vehicles to move from place to place, highways have become pathways or vectors for the spread of invasives. Human actions are the primary means of invasive species introductions. For example, Canada thistle, *Cirsium arvense*, arrived from Europe in the 1600s as a contaminant in crop seed. It is now on most noxious weed lists in North America. Purposeful introductions of invasives have resulted from the use of such species as ornamental, pasture grasses, or to solve erosion control problems. Both intended and unintended introductions are now equally common.

Most states confine their noxious weed lists to agricultural concerns rather than using the definition of invasive to expand coverage of the laws and regulations beyond those species with a wider span of harm. Noxious weeds are plants deemed by a state's Department of Agriculture (DOA) and/or Department of Natural Resources (DNR) as harmful to agriculture, human health, or the environment.

RISING COSTS IMPOSED BY INVASIVE SPECIES

Introduced organisms are the second greatest cause, after habitat destruction, of species endangerment and extinction worldwide (*6*). In the United States, nonindigenous species do more than $130 billion a year in damage to agriculture, forests, rangelands, and fisheries, as estimated by Cornell University biologists (*7*). According to an Office of Technology Assessment study, a selection of just 79 of these non-native species cost the American taxpayer some $97 billion in damages to natural resources and lost industrial productivity during the 20th century (*8*). Some of these costs arise from both roadway management needs and impacts on adjacent landowners (*9*):

- Contamination or competition with crops,
- Decrease in forage value of rangeland and pastures,
- Change in aesthetics of the landscape and degradation of natural heritage and educational value,
- Increase in fire threats,
- Compromise of roadside visibility and safety,
- Attraction of wildlife to roadside, and
- Additional costs of roadside maintenance.

Such costs are increasing as invasive plants spread into an estimated 4,600 acres daily (*9*). In the 2002 report, *Invasive Species: Clearer Focus and Greater Commitment Needed to Effectively Manage the Problem* (*10*), the U.S. General Accounting Office (GAO) found that most economic estimates do not consider all of the relevant effects of non-native species or the future risks that they pose, but that a more comprehensive analysis could help decision makers make better resource allocations; that is, allocate more resources to the task.

A number of DOTs noted that access to information about the costs and benefits of treating invasive species could bolster their ability to get resources allocated to address the problem. Invasive species and their management impose substantial costs on DOTs, and a number of states, associations, and scientific entities have begun to compile these data. Historically, roadside vegetation restoration and maintenance has been a lower priority than safety-related issues such as pavement management and snow and ice control. However, in recent years, public scrutiny has broadened from these core issues to the effect and appearance and ecological function of the roadside as well.

FEDERAL CONTEXT, PRIORITIES, AND DRIVERS IN INVASIVE SPECIES CONTROL

Invasive species are an increasing concern for all public agencies. In many cases, the control of invasive species is mandated by state and local law and policy; in others, control of invasives depends on voluntary efforts and the public interest missions of public agencies.

Presidential Executive Order 13112 on Invasive Species and FHWA Guidance

E.O. 13112 directs all federal agencies to address invasive species concerns and refrain from actions likely to increase invasive species problems. It also directs agencies to "provide for restoration of native species and habitat conditions in ecosystems that have been invaded." On August 10, 1999, FHWA provided field guidance on implementing the executive order, which specified that (*11*):

- Federal funds cannot be used for construction, revegetation, or landscaping activities that purposely include the use of known invasive plant species as listed by some states or the National Invasive Species Council (NISC).
- National Environmental Policy Act (NEPA) analyses require determinations of the likelihood of introducing or spreading invasive species and a description of measures being taken to minimize their potential harm.
- With regard to construction and maintenance, federal-aid funds can be used for new and expanded invasive species control efforts under each state DOT's roadside vegetation management program.

Despite allowances for use by maintenance, thus far redirection of federal-aid funds by states for this purpose has been limited. The executive order and implementing guidance also recommended prevention and eradication measures such as:

- Statewide, right-of-way (ROW) inventories of vegetation that map existing invasive plant infestations;
- Inspection and cleaning of construction equipment;
- Commitments to ensure the use of invasive-free mulches, topsoils, and seed mixes; and
- Eradication strategies to be deployed should an invasion occur.

A number of DOTs have started completing invasive species surveys for all projects (state and federal) with ground-disturbing activities. If weeds are found and adjacent lands are federal, the DOT coordinates with that agency for more effective control of invasive species. Special mitigation measures to prevent the spread of weeds found and to prevent the introduction of invasive species are incorporated into NEPA documentation and contract specifications. Coordination among environmental, design and landscape architecture, and construction staff is on the increase, addressing environmental impacts and eradication and control of invasive species during and after construction. For example, New York State DOT (NYSDOT) and Utah DOT (UDOT) are including invasive species in NEPA decision-making processes, documenting potential environmental impacts, and listing appropriate best management practices (BMPs) as mitigation commitments for all projects that have the potential to spread or introduce listed weeds.

Interagency Invasive Species Council and National Invasive Species Management Plan

E.O. 13112 also created an interagency Invasive Species Council and called for a National Invasive Species Management Plan to better coordinate federal agency efforts. The National Invasive Species Management Plan identifies transportation facilities as sites of invasive species or the means for introduction and spread of invasive species. Some of the other activities of the Council include:

- Identification of sanitation and exclusion methods for preventing the spread of invasive species (e.g., restrictions on use of contaminated soils and fills, cleaning firefighting equipment before deployment to new areas, requiring pest-free forage and mulch and weed-free sod, washing construction equipment, and managing ballast water).
- Development of draft legislation to authorize matching federal funds for state programs to manage invasive species, including a provision to provide assistance to states for the development of state invasive species management plans. The draft legislation proposal may also include tax incentives or other provisions to encourage voluntary participation of private landowners in control programs and to promote their actions to prevent the spread of invasive species. Consideration will also be given to extending current federal authority to conduct control activities on state and private lands where invited by the landowner.
- U.S. Department of Agriculture (USDA) leadership, in consultation with regional, state, tribal, and local agencies, in the formation of a proposal for accelerating the development, testing, assessment, transfer, and post-release monitoring of environmentally safe biological control agents and submit the proposal to the council for review.
- Development of guidance for ranking the priority of invasive species control projects at local, regional, and ecosystem-based levels.
- Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW) is currently updating the Weed Fact Book (*12*) and has proposed an Invasive Biological Control Fact Book. The Federal Interagency Committee for Invasive Terrestrial, Animals, and Pathogens is a newly formed interagency committee undertaking projects similar to FICMNEW (*13*).

A 2003 GAO report claimed that "the federal government had made little progress in implementing many of the actions called for by the plan" owing to delays in establishing teams to be responsible for guiding implementation of the planned actions, the low priority given to implementation by the NISC and federal agencies, and the lack of funding and staff responsible for doing the work" (*14*). State officials who responded to GAO's survey identified a number of gaps in, or problems with, existing legislation addressing invasive species along with other barriers to managing invasive species, including a lack of legal requirements for controlling invasive species that are already established or widespread. Also lacking were federal funding for state invasive species efforts, public education and outreach, and cost-effective control measures (*14*).

Existing Federal Legislation

The most recent transportation legislation, SAFETEA-LU, Section 606, makes existing National Highway System/ Surface Transportation Program funds available for participation in the control of noxious weeds and establishment of native species. Environmental restoration may be carried out for "environmental degradation caused wholly or partially by a transportation facility." Such restoration costs are not to exceed 20% of the total cost of the reconstruction, rehabilitation, resurfacing, or restoration of the facility. Section 329 details eligibility for control of noxious weeds and establishment of native species, if related to transportation projects. Plant establishment and "management of plants which impair or impede the establishment, maintenance, or safe use of a transportation system" are also eligible. This establishment and management may include:

- ROW surveys to determine management requirements to control federal or state noxious weeds, as defined in the Plant Protection Act (7 U.S.C. 7701 et seq.) or state law, and brush or tree species, whether native or non-native, that may be considered by state or local transportation authorities to be a threat with respect to the safety or maintenance of transportation systems.
- Establishment of plants, whether native or non-native, with a preference for native to the maximum extent possible, for stormwater abatement, soil stabilization, and aesthetic enhancement.
- Control or elimination of plants that impair or impede establishment, maintenance, or safe use of a transportation system.
- Elimination of plants to create fuel breaks for the prevention and control of wildfires.
- Training.

These activities "may be carried out concurrently with, in advance of, or following the construction of a project funded under this title." Thus, invasive species control and native revegetation projects may be conducted essentially independently of a transportation improvement project, but should be associated with a current, past, or future project, in some way, not to exceed 20% of the total cost of that project. Because SAFETEA-LU was just recently passed, FHWA has yet to issue guidance to states on the implementation of these provisions.

The Plant Protection Act (2000) replaced the Federal Noxious Weed Act and consolidates and modernizes all major statutes pertaining to plant protection and quarantine (Federal Noxious Weed Act and Plant Quarantine Act). It permits the Animal and Plant Health Inspection Service (APHIS) to address weed issues, increases the maximum civil penalty for violations, and authorizes APHIS to take both emergency and extraordinary emergency actions to address incursions of noxious weeds. In general, this legislation deals with quarantine and inspection, rather than wide-ranging species. A few exceptions have occurred by state request. The National Invasive Species Act (1996) reauthorized and amended the Non-Indigenous Aquatic Nuisance Prevention and Control Act of 1990 to mandate regulations to prevent the introduction and spread of aquatic nuisance species into the Great Lakes through ballast water and authorized funding for research on aquatic nuisance species prevention and control for the Chesapeake Bay, Gulf of Mexico, Pacific Coast, Atlantic Coast, and San Francisco Bay–Delta Estuary. It required a ballast water management program to demonstrate technologies and practices to prevent non-indigenous species from being introduced. The legislation also modified the composition of the Aquatic Nuisance Species Task Force.

Federal Weed Lists

The federal noxious weed list falls within International Plant Pest Convention rules for international trade. Federal listing makes a plant a quarantined pest and an interdiction target. The federal noxious weed listing is designed for species that are not widely distributed and are under official control. Plants would be unlikely to be added to the list if they were widely distributed, unless present in relatively few states. Even then, the federal noxious weed focus of exclusion and eradication does not match well with state noxious weed lists and objectives, which are oriented to the control and management of pest species. In most cases state-listed noxious weeds are widespread, although some states may also have identified a relative few eradication and Early Detection and Rapid Response (EDRR) targets.

There are federal procedures for listing species that are known to be invasive. Such listings may be petitioned and involve stakeholders and the public in the course of the rule-making process. Importation and interstate transport is prohibited for species that are federally listed as noxious weeds or injurious wildlife, although enforcement of prohibitions on listed species and exclusion of invasive species is limited

and largely dependent on inspection services at ports of entry. Federal lists and regulations include the following:

- Federal Noxious Weed List (9/8/00), Plant Protection and Quarantine, APHIS, USDA.
- Federal Plant Quarantine Summary (March 2003), Plant Protection and Quarantine, APHIS, USDA.
- Injurious Wildlife Species List (50 CFR 16.11-16.15), Division of Environmental Quality, U.S. Fish & Wildlife Service (FWS).
- Plant laws and regulations, National Plant Board.
- APHIS regulations (Title 7, Subtitle B, Chapter III, 2000 ed.), USDA.
- APHIS Regulated Plant Pest List, USDA.

STATE AND LOCAL CONTEXT AND PRIORITIES

Given diverse environments, state DOTs attend to state and often local priorities in the management of weeds and/or noxious species. In particular, DOTs may focus on species of concern to safety and/or existing vegetation where the DOT is responsible for managing in the ROW.

State Noxious Weed Laws and Weed Lists

Most state legislatures have enacted noxious weed laws to limit economic loss resulting from the presence and spread of noxious weeds. The laws mandate the control of weed species. A typical noxious weed definition is "A plant which when established is highly destructive, competitive, or difficult to control by cultural or chemical practices." State-specific laws and regulations pertaining to noxious weeds and invasive species are available for review on the Internet. A complete overview of state legislation regarding invasive species may be found in the Environmental Law Institute report, *Halting the Invasion: State Tools for Invasive Species Management* (*15*). Of the thousands of introduced species, each state with a noxious weed list specifies a small number of its own priorities, lending much fragmentation to the pursuit of interstate invasive species priorities.

More than half of responding state DOTs (23) reported that they have an enforceable invasive species law, whereas one-third noted that there was no enforceable invasive species control law. Where a state law does not exist, executive orders by the governor have been issued, as in the case of New Mexico. Elsewhere, as in New York, bills have required the convening of an Invasive Species Task Force to assess the issue and existing programs and recommend future actions to the governor. In Wisconsin, there is a noxious weed law with penalties; however, no agency has been given the authority to enforce it. Missouri DOT (MoDOT) reports that legislation or state legislative allocations have "blurred the picture," cutting support to counties or at the state level. Some DOTs noted that important invasive species are not listed with regard to their state's noxious weed law.

State noxious weed laws often establish weed control boards, which update the state's noxious weed lists. Most states develop and maintain noxious weed lists particular to issues and species of concern in their state, and these are predominantly agricultural. Eleven states still do not have lists and many state weed laws are not enforced. In the past, a lack of coordination has resulted in some DOTs continuing to plant species that are contained on state noxious weed lists.

Lists are sometimes divided into multiple categories. Class A weeds, for example, are usually of the highest priority. They are non-native species with a limited distribution. Prevention and eradication may be required for Class A species. Class B species may be designated for control in regions where they are not yet widespread to prevent further infestation in the state. Where Class B species are already abundant, containment is the primary goal. Class C weeds may already be established throughout much of a state. Long-term programs of suppression and control are a local option, depending on local threats and the feasibility of control in local areas.

Local and Regional Weed Control Efforts

Fragmentation and diverse focus characterize existing local and regional weed control efforts. DOTs often become involved in other regional weed control or cooperative weed management projects. DOTs partner with other major landowners and weed control organizations to more effectively limit the introduction and spread of invasive weed species. Some states, such as Washington, have a strong locally based organization and legal process for managing invasive plant species; the existence of noxious weed control boards in all 39 of Washington's counties creates a framework for coordination of weed management across property lines and political boundaries.

Weed Management Areas (WMAs) are developed by landowners and managers in a common local area to facilitate cooperation in managing common weed problems and preventing the reproduction and spread of weeds into and within the WMA. They bring together landowners and managers (private, city, county, state, and federal) in a county, multicounty, or other geographical area to coordinate efforts and expertise against invasive weeds. The WMA functions under the authority of a mutually developed Memorandum of Understanding (MOU) and is subject to statutory and regulatory weed control requirements. In some states, such groups are initiated by the county agricultural commissioner's office or a federal agency employee, and voluntarily governed by a chairperson or steering committee. WMAs are unique because they attempt to address both agricultural weeds and wild land weeds under one local umbrella organization.

A WMA replaces jurisdictional boundaries that are barriers to weed management programs in favor of natural or

more logical boundaries that facilitate weed management and control. WMAs typically have similar characteristics such as geography, weed problems, climate, common interest, or funding support. Boundaries may be a watershed or other geographic feature. Stakeholders in a WMA jointly prioritize weed management efforts based on species or geographical area. They then work together to manage the weeds within the WMA (*16*).

Regional weed control efforts may cross state and even international borders. The Weeds Across Borders project in the Okanogan region of north-central Washington State and south-central British Columbia involves agencies and major landowners on both sides of the international border. Initiated with partial funding by FHWA, the project has included:

- Development and maintenance of a geographic information system (GIS) inventory of the most problematic weed species.
- Coordination of on-ground treatments of all significant infestations.
- Introduction of a biological control program for several of the widespread invasive weed species.
- Development and implementation of an education program for the public and for lawmakers at the local, state, and federal levels.

The *Cooperative Weed Management Area* (*CWMA*) *Cookbook* (*17*) is a guide to help organize, develop, and operate successful WMAs.

Statewide Invasive Species Councils or Task Forces

Statewide invasive species councils or task forces have been formed in 30 states, according to the 40 state DOT respondents, with the DOT actively involved in all but 4 of those cases. However, only 16 of the 30 state DOTs with such task forces view the council or task force as a success. When asked for further comment on the key strengths, successful approaches, or accomplishments that may serve as models to others, DOTs noted that, at a minimum, the networking paid off. Additional strengths were/are:

- Statewide focus and inclusion of a wide range of interests (e.g., aquatics, horticulture, agriculture, forestry, academics, private land owners, government agencies, extension, industry vendors, and private consultants), their expertise, and the willingness of each member to participate in the council and its subcommittees.
- Creation and wide circulation of a brochure featuring the state's "10 Worst Invasive Weeds."
- Initiation of the production (largely funded by the DOT—Alabama, in this case) of a one-hour documentary on the impact of invasive weeds on the state, to be aired on public broadcasting stations throughout the state and then made available, with text curriculum, for use in all state schools.
- Bringing legislative focus to the issue of invasive species, and the most troublesome species in particular.
- Fostering education and cooperation across multiple jurisdictions.
- Hosting regional, multistate meetings.
- Stopping the sale of invasive plants in the state and compiling a list of noninvasive replacement plants (Connecticut).
- Sponsoring a central and very active website and very active listserv/e-mail list (Hawaii).

In a few cases, "affected parties, such as those responsible for managing ROW are not included in the state's efforts." In another case, the DOT noted that the group "needs to finish the plan and strategies so we can do a better job suppressing/preventing the (species) that we all agree on." The participants typically have "limited time available—most members are busy with other commitments and responsibilities"; however, "with limited budgets the Council is able to address statewide concerns and utilize the limited monetary resources where they will be most effective."

STATE DEPARTMENT OF TRANSPORTATION DRIVERS, PRIORITIES, AND CHALLENGES

For years, DOTs have been managing species that affect roadway safety, sign visibility, and roadside maintenance and operations. The further spread of invasive species, the impact on vegetation management, and increasing attention devoted to the topic by other agencies and stakeholders concerned with the loss of natural habitats have driven additional efforts.

Impact of Executive Order 13112 on State Departments of Transportation

Of all respondents, 33% indicated that E.O. 13112 has notably changed how they do business. A DOT for whom business has changed significantly as a direct result of the executive order had this to say:

> The issuance of E.O. 13112 has changed the program from mainly a control program to some movement towards an integrated management approach. This movement is in its infancy with limited projects and results.

The New Mexico DOT stated that, "As a result of the 1999 E.O., NMDOT adopted a statewide program that includes preventative measures, mechanical control, chemical control, and integrated methods"—characteristic of an IRVM program. Other program changes cited included conducting invasive species surveys for all projects with ground-disturbing activities and coordination with agencies that manage adjacent lands. Special mitigation measures to prevent the spread

of identified patches of invasives and to prevent introduction elsewhere are incorporated into NEPA documentation and contract specifications.

In planning and development, more emphasis is being placed on identifying and controlling or eradicating invasive species before and during construction. For example, UDOT formed a Quality Improvement Team to identify appropriate strategies to implement E.O. 13112 after FHWA issued its guidance. Individuals from FHWA and UDOT design, construction, maintenance, and environmental divisions participated on the team, which agreed to address invasive species on both the state and county noxious weed list. In addition to addressing and proposing mitigation for potential impacts from invasive species as part of the NEPA process, the team identified BMPs to minimize the introduction and spread of listed noxious weed species. These BMPs are included in plans and specifications through a special provision on Invasive Weed Control. UDOT has enhanced training for staff to understand the executive order and its implications, current invasive species problems, and how to incorporate BMPs.

Many DOTs had already begun to require the use of native species; however, the executive order provided a definition of invasive species and elevated attention to the issue at an earlier point in the transportation process. Several DOTs reported that the executive order has given them more justification for actions already underway. NYSDOT noted that, "The E.O. added emphasis and formality to an issue that although recognized as important, had not been formally addressed in Department policy, guidance, and procedure."

Although most DOTs noted that E.O. 13112 had not really changed how the agency does business, many of these noted that it has added steps or work in planning or project development. Twenty-five percent indicated that their agency is currently incorporating invasive species assessments in all NEPA evaluations. Another 18% ensure that invasive species assessments are at least incorporated in Environmental Impact Statements (EISs) or environmental assessments (EAs).

Although overall business practices may not have changed much in ways that can be directly attributable to E.O. 13112 for two-thirds of the respondents, DOTs have increased their activity and attention in the area and new policies and procedures have been added in recent years. Many DOTs are now targeting specific species rather than weeds more generally. One DOT indicated that it is attempting to include invasive species as a bid item for federal-aid projects. DOTs are eliminating the use of invasive plants and removing some existing plants as part of landscaping projects. Certified weed-free hay or mulch is now required. At the Colorado DOT, maintenance staff is now included in construction project final inspection. Some DOTs mentioned that they could do more to implement E.O. 13112, but resource availability is a major issue.

State Department of Transportation Priorities in Invasive Species Control

Transportation agencies manage approximately 12 million acres of land surrounding state, interstate, county, and municipal roads. In the survey conducted for this synthesis, responding state DOTs identified 68 different invasive species, nationwide, in their lists of "top five" invasive species in each state.

Some top priorities are widespread; one-third of the respondents placed Canada thistle and 30% placed Johnsongrass (*Sorghum halepense*) on their lists of top invasives. Twenty-five percent are fighting kudzu (*Pueraria montana*), which has been moving westward, and 20% and 18% are targeting Japanese knotweed [*Fallopia japonica* (syn *polygonum cuspidatum*, *F. x. bohemica*, *F. sachalinensis*) and Purple loosestrife (*Lythrum salicaria*)], respectively.

With regard to non-plant and weed species, 13% of respondents control for mosquitoes to prevent the spread of West Nile Virus and 13% control for red imported fire ants (*Solenopsis invicta*). Of responding DOTs, 8% control for gypsy moth (*Lymantria dispar*) and 5% for oak wilt (*Ceratocystis fagacearum*). Eight percent control zebra mussels (*Dreissena polymorpha*). However, weed species occupy a larger part of the time, energy, and budget of invasive species control and are the primary focus of this report.

Primary Department of Transportation Drivers in Addressing Invasive Species

More than two-thirds of all respondents (68%) reported that internal, rather than external policies drive their efforts at invasive species control. Figure 1 details the percentage of respondents citing different categories of drivers in addressing invasive species.

For several DOTs, state laws on invasive species or noxious weeds drive their efforts. Other agencies may require DOTs to address invasive species as a condition of acquiring permits. State DOAs often play a key role. In addition to a coordinating role, some DOAs have helped implement controls on DOT ROWs. Invasive species committees, task forces, and weed management groups also provide input.

Despite these important inputs, leadership from within propels many DOT invasive species efforts. Members of roadside management teams or landscape architects were mentioned as being instrumental in guiding invasive species policies and finding ways to further invasive species control in a low-resource environment. DOTs also identified specific concerns and objectives as drivers, such as reducing herbicide use, protecting rare or threatened species, and carrying out formal roadside vegetation management plans. Cost-efficiency and environmental concerns are also increasingly

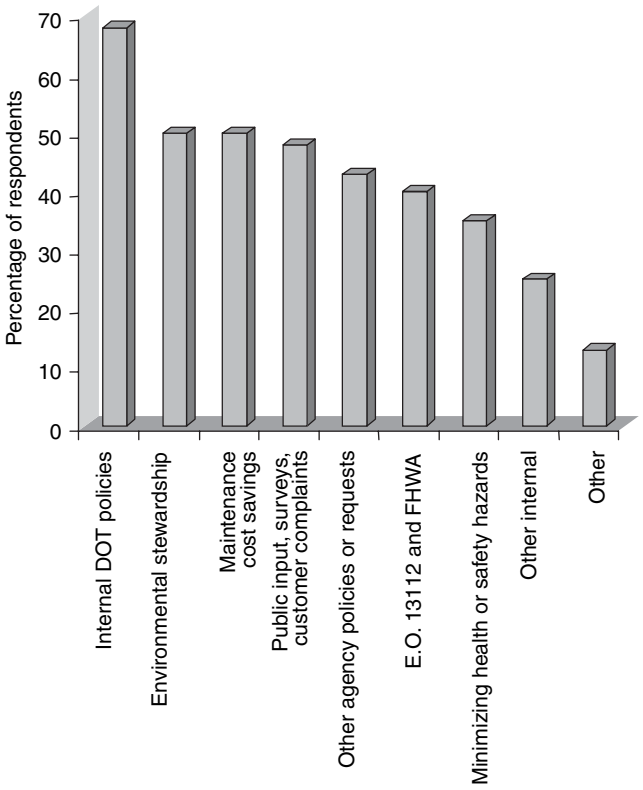

FIGURE 1 Drivers in addressing invasive species.

an issue. One DOT cited invasive species control as an important factor in pavement preservation.

Primary Obstacles to Control of Invasive Species

Many DOTs were quite vocal about the obstacles confronting the control of invasive species. For many, a simple lack of resources—both dedicated funding and dedicated personnel—is at the heart of insufficient invasive species control. As NYSDOT stated, "[c]urrently, staffing, and funding for invasive species management must compete against other priorities for the same staff time and funds—dedicated line items and a separate funding source would be a great benefit." The frequency at which respondents cited various categories of obstacles is illustrated in Figure 2. Fifty-three percent of responding DOTs cited a lack of state funds as an obstacle in invasive species control, 50% cited a lack of control over lands adjacent to the ROW, and 38% reported that limited federal highway funds were a primary obstacle.

Another major hurdle is that the concept of invasive species has not been adequately defined, if at all, and there is little legal impetus or even guidance for addressing invasive species control. The laws of many states still only address

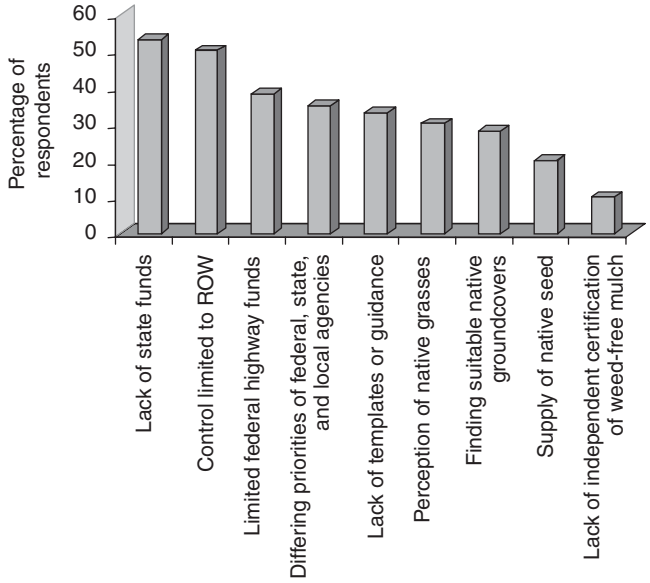

FIGURE 2 Obstacles faced by departments of transportation.

noxious weeds identified for agricultural purposes. Thirty-five percent of responding DOTs cited differing priorities of federal, state, and local agencies as obstacles to invasive species control. Inadequate or incomplete inventories of invasives, as well as the means to track those species identified, remain obstacles for others.

Other obstacles cited by individual DOTs included the following:

- Mitigation measures, such as washing equipment before and after construction and site-specific collaborative mitigation, all add cost, usually to the construction budget, and monitoring these measures during construction is difficult.
- Inadequate specific guidelines or policies on a programmatic scale.
- Poor soil, compacted soils, disturbed and degraded roadsides.
- Lack of an easy (commitment) tracking system for segments of ROWs that come under federal funding for purposes of compliance with E.O. 13112 at any given moment. The status needs to be easily accessible to maintenance personnel as projects close and landscaping and maintenance projects start and close.

Getting the right information to the right people was a concern for some DOTs. As one noted, the problem is "[l]ack of communication, lack of training for contractors, and overall lack of awareness in the organization, especially in that this is a serious issue." Others lack good training materials or management guidelines.

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CHAPTER THREE

PREVENTION OF ROADSIDE INFESTATIONS

The first line of defense and the most cost-effective strategy against invasive species is preventing them from invading and becoming established in the first place. Once an infestation becomes well-established, management is expensive and eradication is difficult and unlikely. One of the most important components of prevention is the detection of individual plants or small groups of plants after seed germination. The second is eradication before they produce seed or develop an established root system.

Early detection, as applied to invasive species, is a comprehensive, integrated system of active or passive surveillance to find and verify the identity of new invasive species as early after entry as possible, when eradication and control are still feasible and less costly. It may be targeted at areas where introductions are likely, such as near pathways of introduction and sensitive ecosystems where impacts are likely to be great or invasion is likely to be rapid (*18*). After invasive species become established, they often grow deeper root systems and may reproduce by rhizomes as well. Control after weeds have gone to seed may begin a long process, because many seeds are viable for years. Control of non-plant species requires equally attentive action and may reach out to law enforcement, recreational users, and travelers, especially users of aquatic vehicles that may carry infested water from one location to another.

Focusing resources on preventing and detecting new invasions, to the extent possible, can be far more cost-effective than containing existing populations. As the National Invasive Species Action Plan notes, "[e]ven the best prevention efforts cannot stop all introductions. Early detection of incipient invasions and quick, coordinated responses are needed to eradicate or contain invasive species before they become too widespread and control becomes technically and/or financially impossible. Populations that are not addressed early may require costly ongoing control efforts."

The remainder of this chapter focuses on Early Detection and Rapid Response (EDRR), planning for invasives control, identification of aspects of operations that spread invasive species, roadside inventory, risk assessment, priority setting, and information management.

ASSESSMENT AND MANAGEMENT

Management of invasive alien species generally includes:

- Initial assessment of the situation;
- A process of identifying the species of highest priority for a management program;
- Detailed information on methods for eradication, containment, control, and mitigation;
- An introduction to monitoring approaches;
- Identification of principal approaches to the project;
- Activities to secure resources;
- Stakeholder commitment and involvement; and
- Training in control methods.

The first step of a management program is to assess the current situation by determining the management goal, the extent and quality of the area being managed, the invasive target species affecting the area, and the native species threatened. The management goal should be the conservation or restoration of intact ecosystems that support the delivery of ecosystem services and cost-effective maintenance of the area. Eradication and control options need to be evaluated on the basis of the likelihood of success, cost-effectiveness, and any potential detrimental impacts.

Prioritization of invasive species control projects takes into consideration the extent of the area infested by the species, its impact, the ecological value of habitats invaded, the difficulty of control, and management costs. Species with the highest priority would be those known or suspected to be invasive but still in small numbers, species that can alter ecosystem processes, species that occur in areas of high conservation value, those imposing or with the potential to impose high costs on the DOT, and those that are likely to be controlled successfully.

Eradication, containment, and control are all approaches to management of populations of invasive species. When prevention measures have failed, an eradication program is considered to be the most effective action, because of the opportunity for complete rehabilitation of the site and long-term minimization of costs. Because eradication programs can initially be costly and require full commitment until completion, the feasibility of this approach requires careful consideration. Eradication has been achieved using

mechanical, chemical, and biological control, as well as habitat management. These methods are discussed in detail in chapter four.

Identifying Major Pathways and Managing Risk

The most common approach for prevention of invasive organisms is to target individual species. A comprehensive approach also targets major pathways that lead to harmful invasions and manages the risks associated with these pathways. Although some have argued that certain pathways, such as ship ballast water, have already been used for centuries, current attention to control is still important. Establishment rates can vary over time. For example, with faster transport times, some invasive species can establish in new environments more easily. Climatic changes and changes in disturbance in the area of introduction (e.g., construction opening new areas of land or salinity and nutrient changes in bays) also affect an area's susceptibility.

Pathways for introduction of invasive species are both intentional and accidental. Most plant and vertebrate species introductions have been intentional; for example, using plants as ornamentals or for erosion control, mammals as game, birds for enjoyment, fish for sport fishing. In contrast, most invertebrates (including marine organisms) and microbe introductions have been accidental, frequently attached to other species introduced intentionally. Often agricultural weeds have been introduced as contaminants of crop seeds, whereas most of the environmental weeds were purposefully planted as ornamentals, for soil stabilization, or for firewood. Education is a key component of successful prevention and management methods. DOTs, WMAs, and federal agencies have roles in informing the public why prevention measures are taken and what impact failure can cause (*19*).

Identifying Aspects of Department of Transportation Operations That Promote Invasives

E.O. 13112 mandates a risk-based approach, including consideration of the likelihood that an invasive species will establish and spread, as well as the degree of harm it could cause. To do this, it helps to start with a master list of the DOT's work activities that may inadvertently promote the spread of an invasive. A risk assessment identifies the most significant issues and helps decide where to focus. A few DOTs are currently identifying infestations on-site for treatment before ground disturbance, over multiple years if necessary. Increasingly, measures are being taken to conserve valuable topsoil, instead of having it collected and sold by contractors, which leaves deficient soils that are more vulnerable to infestation by invasive species. DOTs are checking and treating permanent water control for West Nile Virus and considering inadvertent creation of such environments as part of current planning processes.

Identification of aspects of operations that may affect the environment is a step in the development of a system to manage environmental impacts, often called an environmental management system (EMS). In an EMS, the transportation agency identifies environmental aspects of its activities, products, or services that it can control and over which it can be expected to have influence to determine those that have had or can have significant impacts on the environment. With respect to invasive species and other environmental impacts, the DOT can then prioritize pathways and controls according to significance, available funding, risk, or any other factors the DOT deems important.

Although research has indicated that off-road vehicles are among the largest offenders in the transport of seeds of invasive species, construction projects, transportation systems, and roadside maintenance operations can inadvertently spread invasives as well. The following are just a few common mechanisms:

- Use of forage mulches that have not been certified weed seed-free mulches and other erosion-control products.
- Planting of species now controlled as invasive for erosion-control purposes, including aggressive sweet clovers, alfalfa, smooth brome, trefoil, and perennial rye.
- Placement of spoil or importation of topsoil contaminated with invasives, such as ragweed, thistles, and sweet clovers.
- Ill-timed maintenance disturbances such as blading, mowing, ditch dredging, and bare-grounding, which have been known to increase invasives.
- Indirect mechanisms such as drainage flows, wind, vehicles, people, and wildlife.
- Movement of construction equipment from a weedy site to a non-weedy site, which can transport undesirable seeds (*9*).

DOT earthmoving, erosion control, water quality, wetland restoration, endangered species protection activities, landscaping, NEPA processes, snow storage, utility line and signage placement, volunteers, recovery zone maintenance, and other maintenance and operations activities all affect invasive species and native habitats. BMPs are used to reduce the introduction or spread of invasive species.

The spread of invasive species caused by substandard vegetation or revegetation and the transport of weed seeds by vehicles are particularly well-documented (*2*). An Australian study found that approximately half of all cars examined were carrying seeds (*3*). Exotic species cover and the number of exotic forb species decreased as the distance from roads increased, particularly on certain soil types (nonserpentine soils in particular) (*20*).

Most DOTs (26 states, 65% of respondents) are not formally identifying aspects of activities that may affect or promote invasive species. Some DOTs reported that they were already "very cognizant of some of the detrimental activities and need to incorporate steps to minimize spread through BMPs." Nine DOTs (23% of respondents) are explicitly identifying aspects or risk areas. At Arizona and New York State DOTs, at the district level, engineers and supervisors are identifying activities such as mowing, blading, and cut cleaning that will promote or spread invasive species, and devising BMPs to reduce these impacts.

New South Wales Roads and Traffic Authority Assessment of Construction, Operation, and Maintenance Activities: Example of Environmental Aspect and Risk Identification

The New South Wales, Australia, Roads and Traffic Authority (RTA) undertakes environmental impact assessments for its construction, operation, and maintenance activities, in addition to project development. The RTA has committed to addressing environmental aspects in all of its activities and to continuously improving the authority's environmental performance. The RTA-wide EMS has been a primary vehicle for accomplishing this commitment. It "provides a structured management system to achieve and demonstrate our environmental performance" (*21*). The RTA prepares a Review of Environmental Factors to identify and consider environmental impacts, which may prompt development and/or implementation measures to address them.

Standard maintenance activities are assessed on a regular basis, usually annually (*22*). Other maintenance activities are assessed in a way similar to that of construction activities (*23*). For maintenance by contract, requirements for environmental impact assessment are incorporated in contract requirements and reviewed by the RTA (*24*). The New South Wales RTA uses tables to summarize construction and maintenance activities and associated environmental aspects and impacts. Activities entailing ground disturbance or use of vehicles and equipment off the roadway have been particularly identified as potentially causing the spread of invasive species.

Risk Assessment

A risk assessment process assesses species based on their perceived risk and potential impact. The objective of the assessment is to predict whether or not a species is likely to become established and be invasive and to generate a relative ranking of risk. Entire pathways may also be analyzed for risk. This may be a more efficient procedure where many possible species and vectors are involved. Although the lack of knowledge and ability to predict consequences may lead to substantial reliance on assumptions, risk assessment provides a logical process for gathering, analyzing, synthesizing, comparing, and communicating information, which can improve the quality of decision making (*25*).

Processes for setting priorities often incorporate risk assessment. One such process is reviewed later in this chapter. Other risk assessment resources include:

- Committee on Environment and Natural Resources, National Science and Technology Council, *Ecological Risk Assessment in the Federal Government* (*26*).
- Commission of the European Communities, *Communication on the Precautionary Principle* (*27*).
- National Research Council, *Risk Assessment in the Federal Government: Managing the Process* (*28*).

PLANNING FOR INVASIVES CONTROL

Once a DOT maintenance staff has determined the problem, it can more easily identify priorities in addressing target species. Such priorities may be determined through a risk assessment, as discussed earlier, after which action plans may be developed. After locating and recording undesirable vegetation on a map, prioritizing sites, and making a realistic assessment of resources to address invasives, a DOT can more readily develop plans, policies, and standards to execute the work.

Fourteen DOTs (35% of respondents) are linking identified locations of invasive species infestation to treatment plans. This occurs in a variety of ways, from highly informal to formal plans. Florida DOT (FDOT) is identifying locations of its two top priority invasive species for treatment planning. At the Arkansas State Highway and Transportation Department (Arkansas Highways), maintenance area personnel identified Johnsongrass for spot control efforts in the course of its other work. Kansas DOT also identifies locations for spot treatment, although on a limited basis. MoDOT tracks and treats sites at the district level, whereas Nevada DOT (NDOT) tracks infestations in stormwater drainage basins and wetland mitigation sites only. At the Wisconsin DOT (WisDOT), district maintenance supervisors work with the county maintenance patrolmen, who are familiar with locations, to develop the annual treatment program, based on county personnel knowledge and experience rather than mapping. In general, these informal systems are handled by DOT regions, districts, or maintenance shops.

Continuous improvement can be accomplished through a variety of means. An EMS encourages a cycle of goal-setting (PLAN), implementing actions (DO), and reevaluation (CHECK and ACT) to achieve continuous improvement with regard to environmental objectives. Although an EMS or EMS-style IVM program explicitly seeks to evaluate procedures, strategies, and implementation for continuous improvement, DOTs use other mechanisms as well. General quality assurance reviews on each district and one of the maintenance areas that FDOT and many DOTs employ, document findings and areas for improvement, which may include invasive species control. Texas DOT (TxDOT) is among those DOTs that are documenting all treatment procedures, but still

working on including feedback and effectiveness information. The statewide consistent pesticide application recordkeeping system that Minnesota DOT (Mn/DOT) and the University of Minnesota are developing for pesticide use and that target species and situations (Canada thistle, guardrails, etc.) is expected to provide data for decision support for continuous improvement, as well. The Adirondack Park Invasive Plant Program (APIPP) and Washington State DOT (WSDOT) have information management and decision support components of their system, as treatment areas are tracked and effectiveness information is gathered. Further information on decision support systems can be found later in this chapter.

Ten DOTs (25% of respondents) revise treatment plans and reallocate resources if necessary and develop systems to document treatment and continually improve coverage. An EMS can help agencies document effectiveness and make the case for additional resources. Because Wyoming DOT (WYDOT) contracts out invasive species control to the state DOA, the state maintenance engineer receives annual reports showing treated areas, cost overruns and underruns, and percentage of ROWs reviewed. It also indicates any problems that were encountered in the program for that year. If there are issues or concerns, these are discussed and addressed with the Wyoming DOA. Wyoming DOA will reallocate statewide funding for the WYDOT noxious weed program if needed. Other states may modify allocations based on district feedback (MoDOT) or on a district-by-district or district-maintenance-area basis (Mn/DOT). Greater flexibility for reallocation is available with a statewide program, with centrally responsible personnel and dedicated funding specifically for control of invasive species (Arkansas Highways). In some cases, treatment procedures may be refined on a central level, with reallocation of resources continuing on the district level (TxDOT). Oregon DOT indicated that it attempts to direct any remaining maintenance dollars at the end of budget bienniums to supplemental herbicide purchases.

INTEGRATED ROADSIDE VEGETATION MANAGEMENT

IVM or IRVM can be considered an outgrowth and subset of Integrated Pest Management (IPM) that has evolved from pest management in agriculture and forestry over the past 30 to 40 years. During that period, pest management evolved from the use of a single control method targeted at a specific pest or group of pests on a crop to an increasingly holistic approach. The development of the concept of IPM was likely the first and largest step, when it was recognized that different pest control methods could be used in combination to achieve the desired pest control and that this desired level of control was within acceptable thresholds, not simply the lowest pest population that could be achieved. Subsequently, workers in the field went on to recognize that pest management should deal with all of the pests affecting a crop in an integrated manner; that is, solving the problem of one pest may simply generate new and often worse problems with other pests. Finally, awareness has been increasing of the costs of chemical pesticides to people and the environment. The conventional wisdom of IPM in agriculture has been that although the broad outline of an IPM system can be prescribed, the local variation in these factors means that the detailed program will end up being location-specific, evolving over time.

IVM or IRVM parallels IPM. IVM or IRVM encourage stable self-sustaining vegetation with limited use of mowing, herbicides, tree removal, and other methods as necessary. Because no single tactic can solve a current weed problem or prevent future infestations, IVM encourages managers to combine several treatment methods into an integrated weed management program tailored to the site and resources available. In addition, an invasive species management program benefits from communication and cooperation among the many individuals and agencies involved in management of the problem. These integrated methods focus on the ultimate goal, which for DOTs may be preservation or the increase of indigenous biodiversity in the conservation area being managed, as well as management of overall maintenance costs.

Planning helps achieve these ends and considers the range of control options. The process of control can be complicated, involving several different tactics in combination or in sequence, or it may be that at its simplest just one method applied using a simple decision rule can suffice to achieve the objective required. For example, for woody invaders, cutting is frequently combined with chemical control to the stump. Control of purple loosestrife may involve biological control, mechanical removal, and other methods. Consideration of the environmental impacts of control actions requires that environmentally sound methods be available and judiciously deployed, especially in highly vulnerable areas. IVM has been described as a decision-making and management process that uses knowledge from a broad base of expertise, a combination of treatment methods, and a monitoring and evaluation system to achieve vegetation management goals. An overview of common IRVM or IVM steps is included as Appendix D. Model DOT IVM or IRVM planning efforts are described in the following section.

Iowa Department of Transportation's Integrated Roadside Vegetation Management

Iowa DOT was an early leader in the implementation of IRVM, which the agency understood as simply using the most cost-effective and ecologically sound method of management on a site-by-site basis. The approach was based on the following principles (*9*).

- Nature does not allow bare soils to exist.
- Bare soils are revegetated by successions of plant groups until a most-fit community of plants develops.
- Disturbance of the vegetative cover reverses the succession of revegetation back to the bare soil starting point and therefore allows more invasions.

Iowa DOT defines IRVM as a long-term approach to vegetation management that (*29*):

- Systematically evaluates each area to be managed;
- Determines which plant communities best fit the area;
- Develops procedures that will encourage, enhance, or reestablish desirable plant communities;
- Provides self-sustaining, diversified, visually interesting vegetation;
- Keeps safety and an improved environment as priorities; and
- Utilizes the most beneficial methods to prevent or correct undesirable situations caused by disturbance or less than optimum vegetative ground cover.

The Iowa DOT's IRVM plan is brief and general, allowing for adaptation by counties. The agency defines the prime purpose of roadside vegetation as holding soil in place without creating hazards. At the same time, it would like to address other desirable uses for roadside vegetation (aesthetic, economic, and environmental) once safety and functional requirements are met. The goals of the Iowa DOT's Integrated Roadside Management Plan are to:

- Preserve and provide safe, functional, and environmentally improved corridors of travel throughout the state.
- Utilize a long-term integrated management program that promotes desirable self-sustaining plant communities and encourage those plant communities that are native to Iowa through preservation and reestablishment whenever practical.
- Bring about considerable reduction and possible elimination of the use of chemicals as a control method of undesirable plants.
- Enhance the scenic qualities of the roadsides and their value as wildlife habitat.

To achieve these goals, Iowa DOT outlined the following procedures, which follow a PLAN-DO-CHECK-ACT (EMS-type) process as follows:

- Inventory the sites to be managed.
- List the existing areas of desirable vegetation, as well as those that need improvement.
- Determine the appropriate management methods needed.
- Determine the best time to implement management procedures and ensure that they are accomplished at that time. Temporary procedures may be needed to preserve an area before permanent procedures can be used.
- Evaluate the results periodically.
- Take further measures if necessary.

The emphasis on weed eradication rather than weed prevention has led to increased mapping of vegetation, statewide planning, and new maintenance and construction practices. Iowa DOT and the Iowa State Legislature have supported establishment of an IRVM center at the University of Northern Iowa, which has produced resources of value to several state DOTs.

Minnesota Department of Transportation Process for Integrated Roadside Vegetation Management Planning

Mn/DOT's process for IRVM planning is detailed in the Minnesota *Best Practices on Roadside Vegetation Management* and summarized here (*30*).

Preliminary Planning, Categorization, and Goals

- A local plan adapted to fit local culture, political concerns, and climate and environmental conditions is best.
- Plan development should be a team effort, with input from those people having expertise in landscape architecture, maintenance, design, construction, biology, horticulture, utilities, and public relations, as well as from general citizens. A steering committee responsible for developing the plan, providing guidance on how it is run, and reviewing the annual work plan and progress may also be created.
  - Before plan development, the agency should identify the roadways it is responsible for maintaining and prioritize them according to the level of management they will receive.
  - When developing the plan and considering maintenance strategies, keep the following guidelines in mind: (1) timing is an important factor for all control and maintenance methods, (2) programs should be kept flexible to allow for changes as needed, (3) a combination of several control methods is usually more effective than any single treatment, and (4) maintenance costs are lowest when programs are planned and completed on schedule.
- Also identify the desired outcome for a given feature. For example, is the objective to have low maintenance, return the roadside to prairie grasses, maintain golf-course-like sod, or reestablish a wetland?

Assessing Existing Conditions

Assess existing conditions to assign and prioritize management strategies for an area. Three factors that will direct management techniques are soil, topography, and vegetation.

- Soil—Understanding the types of soils present and their physical characteristics is important when outlining a plan for roadside vegetation management. Soil type and texture determine vegetation selection, herbicide application rates, fertilization needs, and erosion potential.

Once known, management techniques should be targeted to those conditions. The ideal surface soil is composed of 5% organic matter, 25% air, 45% mineral material, and 25% water. The organic material provides fertility and water-holding capacity and supports microbial life. Oxygen is required for all root growth. Along roadsides, soil is typically stripped of its nutrients and compacted such that little air remains in the soil, leaving a very hostile environment for vegetation to flourish. When trouble shooting to determine causes of vegetation problems, assessing the soils in an area, especially for excess nitrogen, may explain excessive weed growth or resistance to chemical control methods.

- Soil health—Healthy soil is a critical element for establishing a healthy roadside environment. Even the most appropriate and useful tools for managing roadside vegetation may not work if the soil lacks nutrients to support the targeted vegetation. To improve unhealthy soil, try fertilizer, compost, aeration, or deep scarification to incorporate oxygen into the soil. If improving soil health is not possible, choose appropriate vegetation of a type that does not need high nutrient soils to flourish for establishment in that area. One way to assess the health of the soil is to send a sample to the state Extension Service Office for analysis and recommendations on the appropriate type and application rate for any necessary fertilizer.
- Soil considerations for herbicide use—Use lower application rates for coarse-grained soils and higher rates for fine-grained soils or soils high in organic material. Before application, learn the potential for herbicide runoff.
- Native vegetation—There are three main reasons for preserving native plants:
  - Environmental—There are no substitutes for the original wild species of individual states. Once lost, their genetic material can never be recreated. In addition, native wildlife often depends on native vegetation for survival.
  - Economic—Native plant communities are relatively stable and require little maintenance. Natural communities provide good erosion control and are less susceptible to weed invasions.
  - Aesthetic—Native wildflowers and grasses provide seasonal color changes along roadsides, a natural beautification. They also screen undesirable views and objects if planted strategically.

Developing a Plan

After the steering committee or appropriate personnel have been assembled and roadside areas have been categorized, Mn/DOT suggests that an IRVM plan be written, following these steps (*30*):

- Develop a vision or mission statement—Such a vision statement is a picture of a road 10 to 20 years in the future. It includes the highest aspirations for what the roadside can become and serves as a source of motivation for all those involved in the process. A mission statement is broad and outlines the ultimate reason for the program's existence.
- Collect pertinent data, such as costs, vegetation (existing and desired), available personnel, and resources—This step includes reviewing records of current maintenance operations and taking an inventory of current roadside vegetation conditions.
- Establish goals and objectives—When doing so, consider the following basic principles:
  - Safety for the traveling public and maintenance staff,
  - Maintenance of the infrastructure and highway integrity,
  - Cost-effective use of public resources,
  - Environmentally sound decision making, and
  - Needs and concerns of adjacent landowners and the traveling public.
- Analyze and prioritize goals and objectives—Identify which goals are most important. This allows problem areas to be dealt with first, making other goals and objectives easier to reach.
- Assign duties and responsibilities for each program participant—With input from those staff members who will be responsible for plan implementation, assign duties and responsibilities.
- Plan for budget considerations—Identify costs connected with implementing each plan element, as well as ways to deal with budget constraints. This may include planning for equipment purchases and staff needs and increasing the efficiency of existing operations.
- Provide an opportunity for research and innovation—Note research opportunities that may result in innovations for improving quality, reducing costs, and improving working conditions for maintenance staff.
- Provide evaluation criteria—This may be the most important element of the IRVM plan. It is critical that some benchmark be developed to measure program success. Meet and document short-term goals and objectives. Maintain records of implementation activities over time to evaluate overall direction and accomplishments. Periodically evaluate the plan to determine if it is advancing and if it has reasonable and attainable goals and objectives. Make changes as needed.

Implementing the Plan

Mn/DOT recommends the following steps to implement the IRVM plan (*30*).

- Identify appropriate methods and applications for control. This could include mechanical methods, such as mowing and aeration; biological or natural processes; cultural methods, such as appropriate seed selection, planting and mulching, or burning; chemical methods, such as the use of herbicides and pesticides; a hands-off approach; or preservation and conservation.

- Train all staff responsible for implementing each element of the IRVM plan with regard to the plan components and responsibilities. This is especially important for those staff members who will be completing the actual maintenance.
- Keep records of maintenance activities. This includes information about the type of control used, conditions under which it was applied, and general management information. Information about the control method includes weather, application area limits, time of application, concentration, and quantity of any chemicals applied. For general management purposes, hours, personnel, equipment, and costs are needed to set priorities, evaluate cost-effectiveness, and budget time and money for future activities. A complete and continuously updated location map, indicating control activities and dates of application, is recommended. This can be integrated with a GIS to automate the record-keeping process.
- Regularly evaluate the program to measure the success of an IRVM plan. This may include tracking the number of citizen complaints received before and after plan implementation, cost reductions for certain maintenance activities, and allocation of staff time. Evaluate the effectiveness and success of plan elements and make changes as necessary.

New York State's Six-Step Approach to Integrated Vegetation Management Planning and Implementation

In New York State, IVM has been used on powerline corridors for more than 20 years, where a focus on culturing desirable plant communities that minimize the presence of undesirable plants has reduced treatment needs and herbicide use by more than half during that period (*31*, p. v). Nowak and Ballard's work with the utility industry and NYSDOT has involved a six-step approach to IVM that provides a framework for communicating, organizing, and conducting an IVM program (*32*). The following step-wise system is summarized and adapted from Nowak and Ballard's work for the utility industry and U.S. Environmental Protection Agency (EPA) (*32*). It closely parallels that of the Integrated Pest Management Practitioners Association, described earlier.

Step 1: Understand pest and ecosystem dynamics—A first step to conducting IVM is to develop a working knowledge of the organisms in the managed system and how they interact with each other and the environment, with or without vegetation management, to produce ecosystem conditions. It is important to identify and understand:

- Species life histories (reproduction, growth, and longevity), plant strategies, and responses to disturbance.
- Plant succession, changes in distribution, and abundance of plants through time and space.
- How plants and communities can be manipulated to control the rate and direction of plant succession through interference, grazing, and other mechanisms.

Step 2: Set management objectives and tolerance levels—Tolerance levels are specific descriptions of vegetation conditions—individual plant and plant community size, abundance, and composition—that, if exceeded, trigger a need to intervene. Undesirable species are not treated unless they exceed the critical threshold. Well-defined thresholds are a critical element of IVM (*33,34*) that can be useful in communicating management needs to various stakeholders; for example, thresholds and tolerance levels can be used to demonstrate the cyclic nature of vegetation dynamics, which supports a need to control vegetation on a regular basis. Stakeholders include vegetation management professionals responsible for management decisions on a particular ROW, landowners of the ROW or adjacent properties, governmental regulators responsible for administering state and federal policies and laws, and nongovernmental organizations with a general concern for the environment.

Step 3: Compile treatment options—Different treatment options may be needed to match variable environmental and site conditions, concerns, and interests on a ROW. Vegetation treatments can be grouped into categories, such as mechanical, chemical, cultural, physical, biological, and ecological; however, IVM does focus on integrating biological and ecological control into all treatment schemes. Creation of stable, low-growing plant communities is the long-term objective, and biological and ecological control produces a long-term reduction in treatment efforts and a reduction in herbicide use (*35,36*).

Step 4: Account for economic and environmental effects of treatments—Economic and environmental considerations factor into the choice of treatment. Cost-effectiveness may be used as a measure of the success of a treatment in terms of economics, plant community dynamics, and related environmental considerations (*37,38*). Direct costs include labor, equipment, and materials to treat ROW vegetation, whereas indirect costs include the loss of values or services that can result from a treatment. The latter are often associated with water quality, pollution, wildlife habitat, and aesthetics, or other ways that the environment can be degraded. Effectiveness pertains to production of desired vegetation conditions and associated benefits and values with operation and management of the transportation corridor in the public interest, taking environmental interests and values into account. Cost-effectiveness timeframes may be short or long term, and often efforts must be made to balance short-term savings with long-term costs. For example, it may be monetarily less costly to mow an ROW today when compared with the use of herbicides, but mowing may produce higher costs over the long-term, because of short-term control of vegetation conditions and shorter treatment cycles than can be achieved with other treatments (*39,40*). IVM is used to maximize cost-effectiveness of management efforts, minimizing costs while creating the desired vegetation conditions and associated positive values associated with these conditions over the long term.

Step 5: Develop site-specific treatment plans—After developing a suite of treatment options (Steps 2, 3, and 4), and weighing the effects of those treatments on long-term production of vegetation conditions and associated benefits and values, a treatment is chosen by the professional vegetation manager. Prescriptions should not be written for entire ROWs, but should instead be developed for specific sections of any one ROW and the constraints therein. It is important to base treatment choices on inventory and analysis of existing site and vegetation conditions (*41*), particularly because these data will be critical in monitoring outcomes of treatments, as outlined in Step 6. Prescriptions for different areas and circumstances of vegetation management should include:

- Desired future conditions of the ROW area to be treated and
- Description of the treatment as a function of current vegetation conditions and justification of treatments, considering ecological, socioeconomic, and administrative or fiscal factors (*42,43*). Treatment recommendations are the crucial part of the prescription.

Step 6: Monitor outcomes and revise and adapt management plans—Adaptive management incorporates learning from experience (*44*). Monitoring of the effects and performance of various treatments may include:

- Amount of materials used in treatment,
- Treatment costs, and
- Vegetation conditions before and after treatment (e.g., quantification of changes in noxious weed cover).

In addition to vegetative community changes, herbicide residuals with chemical treatments, water quality, and wildlife populations can also be monitored and fed into the next round of treatment planning and decision making. Vegetation conditions are compared with the desired condition set during Step 2, and described in prescriptions during Step 5. Any disparities between "desired" and "achieved" results are investigated, and future treatment options adjusted accordingly. Monitoring ensures that treatment effects are gauged and shortfalls corrected by improving management schemes to better accomplish management objectives.

To What Extent Are You Implementing IVM: A Self-Evaluation

Nowak and Ballard pose a series of questions that maintenance managers may use to self-evaluate their current approach to vegetation management and identify gaps between current systems and the integrated approach presented earlier. Numbers correspond to the steps presented previously (*32*).

1. Do you have a detailed, basic knowledge of the managed ecosystems?

2a. Do you actively involve stakeholders in vegetation management decisions?

2b. Do you consider tolerance levels when determining the need to treat vegetation (positive approach) or do you take a rote approach and treat vegetation only routinely (negative approach)?

2c. Are you proactive in vegetation management (e.g., treat vegetation in concert with tolerance levels, with decisions based on inventory and planning) or reactive (e.g., "hot spotting," where vegetation is treated after thresholds are soon to be, or already, exceeded)?

3a. Do you maintain a broad range of vegetation treatments—mechanical, chemical, cultural, and biological—in your "toolbox," and apply a variety of treatments depending on the site and vegetation conditions?

3b. Do you foster the use of biological and ecological controls to prevent pest populations from building past economic thresholds?

4. Do you use broad considerations of cost-effectiveness in selecting a treatment for a specific site?

5. Do you prescribe treatments in a site-specific manner, based on a contemporary inventory of ROW resources?

6. Do you monitor the results of treatments to compare actual conditions with desired future conditions and look to improve the system based on that comparison?

In 2003, NYSDOT developed the following 10-point invasive transportation vegetation management plan:

1. Develop a prioritized list of threatening flora or fauna based on regional environments.
2. Use field and GIS mapping of existing invasive populations.
3. Integrate invasive species identification and analysis as part of the department's normal NEPA/SEQR (State Environmental Quality Review Act) processing.
4. Evaluate potential impacts caused by construction or maintenance activities.
5. Develop preventive BMPs.
6. Test, execute, and evaluate eradication measures.
7. Review and update annually the vegetation management plans.
8. As innovative design solutions progress, opportunities for the introduction or spread of invasive species are reduced.
9. Promote a climate of interagency cooperation and sharing of coordinated research with public and private sectors.
10. Increase employee and public knowledge through outreach training of the effects of invasive species to the users (*45*).

NYSDOT's Draft "Metric for Assessing Performance of Integrated Vegetation Management on Rights-of-Way"

As part of NYSDOT's evaluation of their current vegetation management program and the agency's Alternatives to Herbicide program, NYSDOT is developing a systematic framework and research protocol for identification, evaluation, and implementation of environmentally sensitive, lower maintenance, and cost-effective vegetation management techniques that can be integrated into the overall vegetation management program (L. Greninger, personal communication, June 1, 2004). To assist NYSDOT in this effort the State University of New York developed the draft "Metric for Assessing Performance of Integrated Vegetation Management on Rights-of-Way" (*46*). Assessments include interdisciplinary field meetings and interviews with staff; visits to a representative sample of roadsides; and review of standard operating practices, vegetation conditions, field performances, site challenges, and vegetation management innovations. A report was developed that presents findings and recommendations associated with each principle and criteria. Each principle will have highlighted strengths and weaknesses and sets of commendations for successes and recommendations for program improvement.

RESOURCES FOR INTEGRATED VEGETATION MANAGEMENT PLANNING

Appendix D includes detailed information on Integrated Vegetation Management Planning. The interagency gateway to invasive species control programs and tools, on the Internet, has a list of management plans that have been developed in each state and by each species. Decision support tools are also available. Readers can reach each of these sites at www.invasivespecies.gov.

Other resources for IVM planning can be found in references *47–52*.

SETTING PRIORITIES

DOTs set priorities in an attempt to minimize the total, long-term workload, and hence the cost of an operation in terms of money, resources, and opportunities. Therefore, invasive species control activities may be focused on the prevention of new infestations and on existing infestations that are the fastest growing, most disruptive, and affect the most highly valued or costly to maintain areas. Also considered is the difficulty of achieving satisfactory control; giving higher priority to infestations the DOT believes to be the most amenable to control with available technology and resources. A detailed priority-setting system for weeds is presented in the *Handbook for Ranking Exotic Plants for Management and Control* (*53*).

The priority-setting process can be difficult, owing to the need to consider multiple factors. It may be helpful to group these factors into four categories as a filter to identify the worst invasives. This process is recommended by the Global Invasive Species Programme (*54*):

1. Current and potential extent of the species on or near the site (primary consideration). Priorities are assigned to species to first, prevent the establishment of new invasive species; second, eliminate small, rapidly growing infestations; third, prevent large infestations from expanding; and fourth, reduce or eliminate large infestations. Priorities should be assigned in the following sequence:
   – Species not yet on the site but which are present nearby. Pay special attention to species known to be pests elsewhere in the region.
   – Species present on the site as new populations or outliers of larger infestations, especially if they are expanding rapidly.
   – Species present on the site in large infestations that continue to expand.
   – Species present on the site in large infestations that are not expanding.
2. Current and potential impacts of the species. The order of priorities under this category is based on the management goals for your site; however, the following order of consideration may be helpful:
   – Species that alter ecosystem processes such as fire frequency, sedimentation, nutrient cycling, or other ecosystem processes. These are species that "change the rules of the game," often altering conditions so radically that few native plants and animals can persist.
   – Species that kill, parasitize, hybridize, or outcompete natives and dominate otherwise undisturbed native communities.
   – Species that do not out-compete dominant natives but prevent or depress recruitment or regeneration of native species, reduce or eliminate resources (e.g., food, cover, and nesting sites) used by native animals, promote populations of invasive non-native animals by providing them with resources otherwise unavailable in the area, or significantly increase seed distribution of non-native plants or enhance non-native plants in some other way.
   – Species that overtake and exclude native species following natural disturbances such as fires, floods, or hurricanes, thereby altering natural succession, or creating situations that hinder restoration of natural communities. In areas of repeated disturbances, DOTs may want to elevate the importance of this category.
3. Value of the habitats/areas that the species infests or may infest. Priorities may be assigned in the following order:
   – Infestations that occur in the most highly valued habitats or areas, especially areas that contain rare

or highly valued species or communities and areas that provide vital resources.
   – Infestations that occur in less highly valued areas. Areas already badly infested with other pests may be given low priority unless the species in question will make the situation significantly worse.
4. Difficulty of control and establishing replacement species. Priorities may be assigned in the following order:
   – Species likely to be controlled or eradicated with available technology and resources and which desirable native species will replace with little further input.
   – Species likely to be controlled but that will not be replaced by desirable natives without an active restoration program requiring substantial resources.
   – Species difficult to control with available technology and resources and/or whose control will likely result in substantial damage to other, desirable species and/or enhance other nonindigenous species.
   – Species unlikely to be controlled with available technology and resources.

Species can be ranked numerically (1, 2, 3, . . ., *n*) or by classifying invasive groups by worst, moderate, and minor. Invasive species whose populations are decreasing or those that colonize only disturbed areas and do not move into (relatively) undisturbed habitats or affect recovery from the disturbance can be assigned the lowest priorities.

Other tools and organizations are readily available to assist DOTs in prioritizing invasive species to target. NatureServe is an independent, nonprofit organization providing scientific information and technology, affiliated with the state Natural Heritage Programs (NHPs). NHPs are often located at state universities and provide support to other government agencies as well as The Nature Conservancy. NatureServe developed an Invasive Species Assessment Protocol, in cooperation with The Nature Conservancy and the National Park Service. The criteria develop Invasive Species Impact Ranks (I-Ranks) at the national and state level. Assessment criteria include Ecological Impact, Current Distribution and Abundance, Trends in Distribution and Abundance, and Management Difficulty. Species ranked high present a severe threat to native species and ecological communities.

Using this new assessment methodology, NatureServe plans to evaluate at the U.S. national level all of the estimated 3,500 non-native vascular plant species established outside cultivation in the United States. That work is expected to assist land managers in prioritizing their work and to support decision making related to prevention, monitoring, management, research, and identifying conservation and preservation areas. FHWA and other federal agencies contributed to the development of this system. Ultimately, the system will:

- Allow management of data through the NHPs' network, using its software, Biotics, and providing access to data through a website.
- Link non-native species to ecological systems.
- Develop more invasive species management information.
- Encourage growth of an EDRR pilot project.
- Model potential sites for non-native invasions.
- Identify invasions that are critical to regional biodiversity resources.

PREVENTION

Prevention involves attention to the most common vectors of transmission, including contaminated seed, mulch, or soils; movement of unlearned equipment or machinery from an invasive weed-contaminated area to a noncontaminated area; and a lack of restoration or revegetation after construction. Prevention depends on limiting the introduction of new weeds through:

- Minimizing the disturbance of desirable plants and soils.
- Maintaining desired plant communities through good management.
- Monitoring high-risk areas such as transportation corridors and bare ground.
- Revegetating disturbed sites with desired plants.
- Evaluating the effectiveness of prevention efforts and adapting plans for the following year.
- Early detection and eradication of small patches of weeds through regulatory inventory and corrective action.

Early detection consists of identifying and documenting the newly introduced invasive weed species in an area. Then, rapid response may be employed to eradicate new infestations and methods may be taken to prevent movement to noninfested areas. Some prevention practices are presented in greater detail in the section of this document on Cultural Control Methods.

Early detection of incipient invasions and quick coordinated responses are needed to eradicate or contain invasive species before they become too widespread and control becomes technically and/or financially impossible. Populations that are not addressed early may require costly ongoing control efforts. For example, spotted knapweed (*Centaurea biebersteinii*) was introduced to Montana in the 1920s, and by 1988 had infested more than 4.7 million acres. The economic impact is approximately $42 million annually (*55*).

Eradication

Eradication is the elimination of the entire population of an alien species, including any resting stages, in the managed area. Efforts at eradication often follow failure to prevent introduction

of invasive species on construction and other vulnerable sites. Eradication as a rapid response to an early detection of a nonindigenous species is often the key to a successful and cost-effective solution. Once invasive species have spread, eradication becomes much more difficult and costly, to the point of being infeasible in many circumstances. Feasibility should be assessed before attempting eradication. Successful eradication programs in the past have been based on:

- Mechanical control—for example, hand-picking of snails and hand-pulling of weeds. Plants are often best eradicated by a combination of mechanical and chemical treatments.
- Chemical control—for example, using toxic baits against vertebrates and spraying insecticides against insect pests.
- Biopesticides—for example, *Bacillus thuringiensis* sprayed against insect pests.
- Sterile male releases—usually combined with chemical control.
- Physical habitat management controls—for example, grazing and prescribed burning.
- Hunting of invasive vertebrates.

If an eradication program is feasible, it is the preferred choice for action against an invasive nonindigenous species. Eradication has the advantage of long-term control; no long-term costs outside of follow-up monitoring and prevention measures and the opportunity for restoration of pre-invasion conditions. However, eradication requires adequate funding and commitment from the stakeholders involved. Well-established populations and large areas of infestation may be unsuitable for eradication programs and may have unintended side effects in addition to very high cost. For example, in the case of the attempt to eradicate South American fire ants in southern states, the insecticide initially was ingested by wildlife and cattle. The ant bait subsequently developed also had non-target effects and proved to be more effective against native ant species than the intruder, ultimately enhancing the populations of the nonindigenous species as a result of a decrease of interspecific competition with the native ant species (*56*).

Eradication (or control) of well-established, nonindigenous species that have become a major element of the ecosystem will influence the entire ecosystem. Predicting the consequences of the successful elimination of such species, including the synergistic effects of the invasive species to indigenous and nonindigenous species can be difficult, but such efforts are important for avoiding unexpected problems. Cases have been reported where one invasive species replaces another, following an effort to eradicate the primary target.

Successful eradication programs tend to involve:

- Small, geographically limited populations of nonindigenous species that are the easiest to eliminate. Therefore, immediate eradication is the preferred option for most species found in early detection surveys. It is crucial that the early warning program has funds available for these actions.
- Situations where eradication is considered feasible and adequate support from stakeholders must be present. This is easier to achieve on construction sites with existing contracts or on other land over which the DOT has control.
- Instances where sufficient funding is secured for an intensive program (allowing for contingencies) to make sure that eradication can be pursued until the last individual is removed. Expectations must be realistic in terms of the processes required for successful eradication programs; for example, low visible returns for high investments late in the program.
- Occasions when immigration of the alien species is zero, something DOTs and contractors can help achieve through vehicle washing and weed seed-free mulch requirements. Potential pathways for the species between infested areas and the management area must be controlled to prevent new invasions.
- Situations where all individuals of the species population are susceptible to the eradication technique.
- Effective team management and motivation. Teamwork is required to achieve an eradication success, with a core of field and research expertise to maximize efficiency and help maintain administrative support.
- A technique to monitor the species at very low densities, at the end of the program, to be designed to ensure detection of the last survivors. Organisms that have less obvious stages and that can survive for long periods; for example, seed banks of weeds need a monitoring period to make sure that eradication has been achieved.
- Methods to minimize the chances of reinvasion and early detection of the eradicated species should it reestablish a need to be in place.

The development and use of field methods is usually an iterative process because implementation needs to be monitored and methods may need to be adapted as conditions change and eradication is approached.

Containment

Containment of nonindigenous invasive species is a special form of control. The aim is to restrict the spread of an alien species and to contain the population within a defined geographical range. The methods used for containment are the same as those described for prevention, eradication, and control. Containment programs also need to be designed with clearly defined goals: barriers beyond which the invasive species should not spread, habitats that are not to be colonized and invaded, etc. To establish these parameters, a clear understanding of why the containment is being done in the

first place is necessary; for example, to protect particular areas or habitats from invasion or to allow time to mobilize other control or eradication measures.

An important component of a containment program is its ability to rapidly detect new infestations of the invasive species both spreading from the margins of its distribution or in completely new areas, so that control measures can be implemented in as timely a manner as possible. Because these new infestations will initially be at very low densities, early detection can be challenging. The invasive species population is suppressed using a variety of methods along the border of the defined area of containment; individuals and colonies spreading beyond this area are eradicated and introductions into areas outside the defined containment area are prevented.

A species most likely to be successfully contained in a defined area is one that spreads slowly over short distances. The nearest suitable habitat for the species should preferably be separated by a natural barrier or an effective artificial barrier. The most suitable cases for containment are habitat islands without suitable connections that would allow the easy spread of invasive species. The spread of alien freshwater species between different parts of watersheds is a good example where containment may be possible.

If containment of an invasive species in a well-defined area is successful, habitats and native species are safeguarded against the impacts caused by the harmful alien species outside this area. In cases where eradication is not feasible and the range of the invasive species is restricted in a rather isolated area, containment of the species in that area can be highly effective in saving other parts even if the species is harmful in the containment area. Containing a species in a defined area will, however, need constant attention and control of the species at the border.

The chances for successful containment of invasive species are relatively good for species living in freshwater habitats; for example, fish spread limited to specific water catchment areas, unless human activities such as artificial canals connect catchment areas and allow alien species to spread between systems.

A related but different approach is exclusion, which aims to protect a sensitive area against invasive species by keeping them out. This method often combines eradication, prevention, and fencing techniques. An area of high conservation value can be enclosed with an animal-proof fence and if the invasive species occurs inside it will be eradicated. This mainland–islands concept is very effective in supporting crucial populations of endangered species, if eradication of the invasive species within the containment area is possible but eradication on a large scale is not feasible. Again, feasibility and potential unintended consequences of the solution need to be examined.

DEPARTMENT OF TRANSPORTATION PREVENTION ACTIVITIES

Just six state DOTs (15% of respondents) believe that they have developed and implemented systems for prevention, detection, analysis, control, and management of invasive species. Eleven DOTs (28% of respondents) have mapped and are currently tracking and monitoring areas of infestation as part of efforts to prevent the spread of invasive species. A similar number have developed policies and procedures to support control efforts and/or implemented IRVM plans, statewide or by district. Six DOTs (15% of respondents) reported that they are reviewing the ROWs and are treating them annually for control of invasive species.

Nevertheless, many DOTs have begun to implement ad hoc policies and practices to control invasive species that may be spread in the course of business. Several agencies are developing more formal, standardized invasive species prevention procedures, practices, and even contract quantities.

Invasive Species Prevention in the Project Development Process

Under E.O. 13112, a federal agency cannot authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species in the United States or elsewhere unless all reasonable measures to minimize risk of harm have been analyzed and considered. To fulfill the objectives of the executive order, FHWA asks that the NEPA analyses include a determination of the likelihood of introducing or spreading invasive species and a description of the measures being taken to minimize their potential harm. Consideration of invasive species should occur during all phases of the environmental process to fulfill the requirements of NEPA. Initial discussions with stakeholders can identify the potential effects from invasive species and possible prevention and control measures (*57*).

Once the plan specified in the executive order is completed, NEPA analyses rely on each state's noxious weed list to define the invasive plants that must be addressed and the measures to be implemented to minimize their harm (*57*). The actual NEPA analysis should include the identification of any invasive terrestrial or aquatic species—plant or animal—that could do harm to native habitats within the project area and could involve mapping all existing invasive populations on and adjacent to the project (*57*). The analysis should also include the potential effect of the disturbances caused by construction on the spread of invasive species and a discussion of any preventative measures or eradication measures that will be taken during the project (*57*). Measures may include inspecting and cleaning construction equipment; ensuring the use of invasive-free mulches, topsoils, and seed mixes; and control and management strategies to be deployed should an invasion occur.

NYSDOT has an invasive species prevention policy and an engineering bulletin requiring designers and maintenance managers—for all projects and activities—to inventory, consider impacts, and incorporate appropriate management techniques for priority invasive plant and animal species (*58*). NYSDOT's Environmental Procedures Manual outlines the following steps for completion during the project development process (*59*):

- During project scoping and State Transportation and Improvement Plan development, inventory project area for priority invasive species (plants *and* animals) and consider possible control strategies. Considering invasive species issues as early as possible is important so that long-term invasive species control strategies can be implemented during maintenance operations, as appropriate, before project construction.
- During project planning, for federally funded projects, complete NEPA checklist and conduct preliminary assessment of priority invasive species issues (plants *and* animals). Also, conduct preliminary assessment for invasive species issues for nonfederally funded projects.
- During project development, review project limits and adjacent areas for presence of priority invasive species (plants *and* animals), note locations on plan sheets, and add information to Regional Invasive Species Inventory. Priority invasive species will include, but not be limited to, purple loosestrife, common reed (*Phragmites australis*), Japanese knotweed, and giant hogweed (*Heracleum mantegazzianum*).
- During project delivery, in consideration of local project area conditions and regional invasive species priorities and management plans; for example, WMAs, APIPP, and Watershed Management Plans:
  - Document invasive species issues in the system used for tracking environmental issues and commitments, and communicate those to other design, environmental, and construction staff.
  - Incorporate, as appropriate, standard specifications, special specifications, notes, and special notes to: (1) limit the additional introduction of invasive species, (2) limit the further spread of existing invasive species, and (3) eradicate and/or control existing invasive species populations. Considerations should include: (1) limiting area and duration of soil disturbance; (2) cleaning construction equipment; (3) limiting construction equipment access and movement within project area; (4) using approved water sources; (5) using native plants and seed; (6) using weed-free planting, bedding, and mulching (straw, wood, and fiber) materials; (7) implementing accepted control and disposal practices; and (8) proper spoil management.

General Weed Prevention Practices for Site-Disturbing Projects in Construction Projects and Maintenance Programs

The following weed prevention practices for construction projects and maintenance programs are synthesized from practices recommended by NYSDOT (*59*) and the U.S. Forest Service (*60*), two of the more complete sets of practices offered by managers of linear corridors in the United States.

- Tools—Provide tools for inspection, enforcement, and results by incorporating, as appropriate, standard specifications, special specifications, notes, and special notes as described in the previous section.
- Identification, awareness, and education—Once it is determined which invasive species are a priority in your area, learn to identify these plants. Improve effectiveness of prevention practices through weed awareness and education.
  - Provide information, training, and appropriate weed identification materials to individuals potentially involved in weed introduction, establishment, and spread on agency lands, including agency managers, employees, contract workers, permit holders, and recreational visitors. Educate them to an appropriate level in weed identification, biology, impacts, and effective prevention measures.
  - Provide proficient weed management expertise at each administrative unit. Expertise means that necessary skills are available and corporate knowledge is maintained.
  - Develop incentive programs encouraging weed awareness detection, reporting, and for locating new invaders.
  - During project construction phase ensure that provisions for location, prevention, and control of invasive species are understood by department construction staff and contractor staff before construction and are implemented throughout the project. Invasive species considerations should be routinely addressed by department staff to contractor staff during pre-bid, preconstruction, get-start, and weekly safety meetings, as appropriate.
- Inventory—Developing an inventory of the priority invasive plants on your site or in your management area is important for several reasons. First and foremost, knowing where the invasive plants live is essential to control efforts; the species will continue to exist and spread until controlled. Also, because new invaders can show up at any time and are the easiest to control when they first arise in an area, regular checking of the site(s) and updating of the inventory is important.
  - Before ground-disturbing activities begin, inventory and prioritize weed infestations for treatment in project operating areas and along access routes.
  - Identify what weeds are on site or within reasonably expected potential invasion vicinity and do a risk assessment accordingly.
  - Any additional priority invasive species populations encountered within the project area during construction should be noted and, if invasive species within the project limits are not adequately controlled, the Regional Maintenance Engineer should be notified

immediately so that controls can be addressed post-construction.
  - To assist with future control efforts, during the operation and maintenance of all elements of the state transportation system, the agency shall initiate a system and regions are encouraged to formally identify and inventory priority invasive species known to exist along the roadside within and immediately adjacent to the ROW. Owing to their heightened role in the introduction and spread of invasive species, priority areas to initiate invasive species inventory efforts shall be the Interstate, expressway, and parkway systems, as practical. Additional priority species and inventory locations may develop as the result of region-wide planning efforts and should also be considered. This inventory should also provide information regarding the extent of invasive species populations adjacent to and outside the ROW. Identified priority invasive species will be considered and managed as appropriate to: (1) limit additional introduction of invasive species, (2) limit the further spread of invasive species, and (3) eradicate or control existing invasive species populations.
- Incorporate weed prevention and control into project layout, design, alternative evaluation, and project decisions.
  - For the site or maintenance program in question, assess weed risks, analyze potential treatment of high-risk sites for weed establishment and spread, and identify prevention practices.
  - Determine prevention and maintenance needs to include the use of herbicides, if needed, at the onset of project planning.
- Control weeds as necessary.
  - Begin project operations in uninfested areas before operating in weed-infested areas.
  - Locate and use weed-free project staging areas.
  - Avoid or minimize all types of travel through weed-infested areas or restrict to those periods when spread of seed or propagules is least likely.
  - Coordinate project activities with any nearby herbicide application to maximize cost-effectiveness of weed treatments.
  - Evaluate options, including closure, to regulate the flow of traffic on sites where desired vegetation needs to be established. Sites could include road and trail ROWs and other areas of disturbed soils.
- Minimize soil disturbance—Owing to the nature of invasive plants to rapidly colonize areas of disturbed soil, out-compete native species, and become firmly established very quickly, it is essential to minimize areas of soil disturbance.
  - For vegetation types with relatively closed canopies, retain shade to the extent possible to suppress weeds and prevent their establishment and growth.
  - Avoid creating soil conditions that promote weed germination and establishment.
  - Minimize soil disturbance to the extent practical, consistent with project objectives.
- Materials sources—Prevent the introduction and spread of weeds caused by moving infested sand, gravel, borrow, and fill material by inspecting material sources on site and ensuring that they are weed-free before use and transport. Treat weed-infested sources for eradication, and strip and stockpile contaminated material before any use of pit material.
  - Inspect and document the area where material from treated weed-infested sources is used annually for at least 3 years after project completion to ensure that any weeds transported to the site are promptly detected and controlled.
  - Maintain stockpiled, uninfested material in a weed-free condition.
  - Avoid or remove sources of weed seed and propagules to prevent new weed infestations and the spread of existing weeds.
- Temporary erosion and sediment control—DOT policy requires sound temporary erosion and sediment control practices on all projects that disturb soil. This practice is particularly important in preventing the introduction and continued spread of invasive plant species. Where invasive species are known to exist, rapid and diligent erosion and sediment control is particularly important.
- Mulch—Owing to the nature of invasive plants to rapidly colonize any area of disturbed soil, it is essential that all disturbed areas be mulched and seeded as soon as possible. If outside the growing season for seed germination, disturbed sites should still be mulched. Sources of mulch should be free of invasive plant parts or seeds. Use of straw or wood fiber mulch is preferred. If hay mulch is used, it should be verified as originating from an invasive-free source.
- Early detection and rapid response—Invasive species, by their nature, spread very rapidly once introduced to a new area. Therefore, it is essential that *new infestations* be identified and controlled as quickly as possible. Control practices for small populations are far more likely to succeed, are significantly less expensive, and provide more options for control methodology.
- Rapid revegetation—Although not a specific condition, replanting or reseeding with native species is highly desired. All of the control methods cited here are intended to reduce or eliminate invasive species so that native species are encouraged to grow and reestablish stable conditions that are not conducive to invasive colonization. In most cases, removal or reduction of invasive populations will be enough to release native species and reestablish their dominance on a site. Replanting may be desirable on private lands, where it can be used as a quid pro quo with the landowner for permission to remove invasive plants. Where project disturbance creates bare ground, consistent with project objectives, reestablish vegetation to prevent conditions to establish weeds.
  - Revegetate disturbed soil (except travelways on surfaced projects) in a manner that optimizes plant establishment for that specific site. Define for each

project what constitutes disturbed soil and objectives for plant cover revegetation.
  - Revegetation may include topsoil replacement, planting, seeding, fertilization, liming, and weed-free mulching as necessary. Use native material where appropriate and feasible. Use certified weed-free or weed seed-free hay or straw where certified materials are required and/or are reasonably available. Always use certified materials in areas closed by administrative order. Where practical, stockpile weed seed-free topsoil and replace it on disturbed areas (e.g., road embankments or landings).
  - Use local seeding guidelines to determine detailed procedures and appropriate mixes. To avoid weed contamination, a certified seed laboratory needs to test each lot against the all-state noxious weed list to Association of Seed Technologists and Analysts standards, and provide documentation of the seed inspection test. There are plant species not on state and federal noxious weed lists that the U.S. Forest Service would consider non-native invasive weeds. Review state and federal lists to determine if any local weeds need to be added before testing. Seed lots labeled as certified weed free at time of sale may still contain some weed seed contamination. Non-certified seed should first be tested before use.
  - Inspect and document all limited-term ground-disturbing operations in noxious weed-infested areas for at least three growing seasons following completion of the project. For on-going projects, continue to monitor until reasonable certainty is obtained that no weeds have occurred. Provide for follow-up treatments based on inspection results.
- Ditching—Many priority invasive plants prefer moist soil conditions and are tolerant of saline environments; therefore, they grow very well in highway drainage ditches and other components of the drainage system. As the dense root systems of invasive plants such as purple loosestrife, phragmites, and Japanese knotweed proliferate, they rapidly clog drainage ditches and reduce sight distances, especially where water velocities slow; for example, the up gradient of culvert inverts and above check dams. As a result of the rapid growth of invasive plants, maintenance cycles are far more frequent where they exist. Before excavating the plants from drainage ditches, the entire invasive plant infestation should be treated with the appropriate herbicide. This will ensure that the plants, seeds, and root parts will not spread and reestablish. Failure to treat the invasive plants before physical removal will most likely result in the immediate regrowth of the plants in the ditch and the spread of the plant to adjacent and downstream areas. In addition, if the invasive plants are not killed before ditch cleaning, the spoil produced can further spread the plants upon disposal.
- Shoulder scraping—Removing the build-up of organic material along highway shoulders is essential to maintaining pavement quality, providing adequate sheet flow drainage and providing safe driving conditions. Owing to their disturbed nature and harsh growing conditions, highway shoulders provide a prime area for invasive plants to establish and spread. Therefore, shoulder scraping activities address invasive plant control, although scraping is not a desirable control method in and of itself. Before scraping highway shoulders, all existing priority invasive plants should be treated with the appropriate herbicide or other control measure to kill seeds and plant parts, including the root stock. This will prevent the plant from reseeding, resprouting in situ, or spreading to adjacent areas by means of water, wind, hitching a ride on equipment, or through spoil disposal.
- Vine, brush, and tree removal—Several common species of vines, brush, and trees that grow readily along highway roadsides are considered invasive species. These species frequently are a nuisance to maintenance workers, block traffic signs, or limit sight distances and therefore are removed in routine maintenance operations. Invasive species should be given preference in the evaluation of these removal priorities and be controlled by accepted practices that will ensure no resprouting and prevent additional spread through seed dispersal. Because these species do not reproduce vegetatively, plant parts do not need to be buried or land filled, and equipment does not require cleaning. Accepted methods of control include foliar herbicide treatment or cutting followed by stump treatment with herbicide. Mowing alone frequently results in resprouting and cloning and is not an effective control methodology.
- Poisonous plant removal—A few invasive species pose a serious threat to worker safety and public health. Giant hogweed is one such plant. On dermal contact this plant causes severe skin burns that are exacerbated through exposure to sunlight. Where this plant is encountered, the location should be located using Global Positioning System (GPS) coordinates and reference marker identification, and the size of the population should be noted and maintained in a regional database.
- Disposal—Proper disposal of harvested invasive plant parts and soil containing invasive plant seeds or root stock (rhizomes) is essential to controlling the spread of invasive plants. Full consideration should be given, as appropriate, as follows:
  - Transportation—While on the treatment site, bag all cut living plant material in heavy-duty, 3 mil or thicker, black contractor quality plastic clean-up bags. Securely tie the bags and transport from the site in a truck with a topper or cap to securely fasten the load to prevent spread of the plant material from the project work site. Transport the material to an appropriate disposal location.
  - Compost—Because of the extremely robust nature of invasive species, composting in a typical backyard compost pile or composting bin is not appropriate.

However, methods can be instituted whereby sun-generated heat can be used to destroy the harvested plant materials. For instance, storage in sealed 3-mil-thick (minimum) black plastic garbage bags on blacktop in the sun until the plant materials liquefy is effective. If a larger section of blacktop is available, make a black plastic (4-mil-thickness minimum) envelope sealed on the edges with sand bags. The plant material left exposed to the sun will liquefy in the sealed envelope without danger of dispersal by wind. The bags or envelopes must be monitored to make sure the plants do not escape through rips, tears, or seams in the plastic.

  - Bury—Owing to the incredible capacity of many invasive species to reproduce by seed, clone, and vegetative propagation, it is absolutely imperative that spoil material contaminated with invasive plant material *not* be disposed of in an indiscriminant manner. It is recognized that the contractor owns spoil material and, therefore, contract documents should identify locations of contaminated soil and address disposal options. Spoil material that contains invasive plant material should be buried in an excavated pit, covered with woven geotextile, and covered with at least 3 ft of uncontaminated fill material.
  - Landfill—If harvested invasive plant parts or spoil material containing invasive plant material is not composted or buried, it should be transported directly to a sanitary landfill for proper disposal.

- Bridge washing—All bridge washing activities, whether for biannual maintenance or in preparation for repainting, require the use of water. Several invasive plant and animal species are aquatic or are dispersed through water; therefore, DOT activities that require the transport and use of water need to consider invasive species control. Control considerations include the use of municipal water sources, filters on water intakes, decontamination and sanitation of equipment, and use of in situ water sources. In addition, the equipment used in transporting and spraying water should be cleaned before use or between uses at sites in different watersheds.
- Construction equipment in water bodies—Several invasive species are aquatic and many additional nonaquatic species are readily spread by flowing water. In addition, many aquatic invasive species are capable of survival out of water for extended periods. To prevent the accidental introduction of invasive species that are "hitching a ride" on construction equipment, all equipment that is to be placed in a water body should be cleaned, as appropriate (e.g., tracks and buckets) to remove invasive species and their seeds and propagules. This requirement applies to equipment arriving on the project and equipment that is being relocated within the project.
- Restricted construction equipment access—To prevent the accidental introduction of invasive plants during construction or maintenance activities, all tracked equipment involved in earthwork should be cleaned to remove plants, seeds, and propagules that may be hitchhiking before arrival on site. If tracked equipment is used in earth work on a portion of a project where invasive species are known to exist, this portion of the earthwork should be conducted last, or the equipment shall be cleaned before use on any portion of the site that is known to be free of invasive plants.
- Cleaning of construction equipment—Cleaning should occur before equipment arrives on site. Once on site, if equipment involved in earthwork is contaminated with invasive species, the equipment should be cleaned before moving into uncontaminated areas. Cleaning shall consist of using physical means and hand tools, such as brushes, brooms, rakes, or shovels, on all track and bucket/blade components to adequately remove all visible dirt and plant debris. If water is used, the water/slurry shall be contained so as to restrict introduction of invasive plants, seeds, and propagules into the project or off site through future surplus material disposal.
  - Treat weeds at administrative sites and use weed prevention practices to maintain sites in a weed-free condition.
  - Determine the need for and, when appropriate, identify sites where equipment can be cleaned. Clean equipment before entering area targeted for prevention of invasives, including federal forest and park lands. When practical, collect and incinerate plant parts. Remove mud, dirt, and plant parts from project equipment before moving it into a project area.
  - Clean all equipment before leaving the project site if operating in areas infested with weeds. Determine the need for and, when appropriate, identify sites where equipment can be cleaned. Seeds and plant parts need to be collected when practical and incinerated.
  - Workers should inspect, remove, and properly dispose of weed seed and plant parts found on their clothing and equipment. Proper disposal means bagging the seeds and plant parts and incinerating them.
  - Set the example; maintain weed-free administrative sites.

Potential Construction Contract Wording and Measures for Invasive Control

The Center for Invasive Plant Management recommends the following contract language for weed prevention (*61*). Before any construction disturbance:

- Identify and map all noxious and invasive weed populations present in the project area.
- Treat or contain any weed populations that may be impacted or disturbed by construction activity.
- Flag all weed populations to be avoided.

- Provide training to construction workers and equipment operators on the identification of weeds to be avoided.
- Certify that all construction material sources used for supplies of sand, gravel, rock, and mulch are weed free before obtaining or transporting any material from them.
- Obtain and use only certified weed-free straw or use fiber roll logs for sediment containment.
- Wash and inspect all vehicles for weed seeds and plant parts before bringing them onto the job site.
- Install stormwater BMPs to prevent erosion of the job site and the potential transport of weedy material onto or off of the job site.

During construction:

- Minimize ground disturbance and vegetation removal as much as possible and practical.
- Wash, or using an air compressor, blow clean all vehicles (including tires and undercarriage) that may have entered weed-infested areas before entering uninfested areas of the job site.
- Restrict vehicles or other traffic that may transport weed seeds or plant material from entering the job site unless they are first washed and inspected.

After construction is complete:

- Revegetate or otherwise prevent the establishment of weeds in all areas of the job site through a program of monitoring and post-construction weed treatment for the life of the project.
- Revegetate using soil components and mulches obtained from non-weed-infested sources.
- Use seed and other plant material that has been checked and certified as noxious weed-free and that has a weed content of 0.05% or less.
- Revegetate using plant materials that have a high likelihood of survival.
- Maintain all planted material and native vegetation located on the project site for the life of the project.
- Monitor all seeded sites for weed infestation. Treat all weeds adjacent to newly seeded areas before planting and treat planted areas for weeds in the first growing season.

NYSDOT uses the following contract item methods of measurement:

- Controlling invasive plants will be measured as the number of square meters of surface area that have been satisfactorily controlled.
- The unit price bid per square meter shall include the cost of all labor, materials, and equipment, including disposal, and incidentals necessary to complete the work.
- Item and pay unit:
  - Controlling invasive plants with plastic (square meter)
  - Controlling invasive plants with herbicides (square meter)
  - Controlling invasive plants by pulling (square meter)
  - Controlling invasive plants by digging (square meter).

EARLY DETECTION AND RAPID RESPONSE

Early detection of nonindigenous species should be based on a system of regular surveys to find newly established species. Methods to detect species differ between taxonomic groups, and their success depends largely on taxonomic difficulties and how conspicuous the species are. A drawback of general surveys is that only well-trained staff will be able to identify nonindigenous species in many taxonomic groups.

Effective Early Detection Programs

A crucial part of early detection is a contingency plan, which determines the action to be taken when an alien species is found. Given the diversity of potential new incursions, the initial plan will be rather general. It should include a list of the stakeholders and experts who need to be contacted for a more detailed action plan. Contingency plans targeted at specific high-risk species can be very efficient, with an exact schedule for what to do. For a contingency plan to work, the equipment needed must be ready at the designated place and funding must be available for emergency eradication or control.

Rapid response is a systematic effort to eradicate, contain, or control invasive species while the infestation is still localized. It may be implemented in response to new introductions or to isolated infestations of a previously established organism that is non-native to the ecosystem. Preliminary assessment and subsequent monitoring may be part of the response. It is based on a system and infrastructure organized in advance so that the response is rapid and efficient (*18*).

When reviewing models of EDRR from oil spills to fire to invasive species and diseases, some of the general features associated with effective EDRR programs are (*18*):

- Strong interest by localities or states in detection and response.
- Federal leadership through means in addition to funding (science, training, logistics, and leadership itself).
- Effective communication of ideas and data with stakeholders and partners.
- Clear organization, authority, and responsibility.
- Exploitation of the most effective means of detection for the particular system.
- Adequate funding.

- Advance, detailed planning of response organization and arrangements.

By means of research for NISC on effective EDRR programs, opportunities for substantial enhancement of passive, early detection could be exploited.

- For each type of invasive species, consideration should be given to advantages and opportunities for passive versus active detection. Most detection of invasive species has been passive, and the approach can be cost-effective when multiple agencies, states, universities, private groups, and amateur biologists are involved.
- Anyone who frequently goes into the field and has some knowledge of biology should be aware of the need for surveillance and enlisted to help. Publicly available, user-friendly databases support EDRR efforts. The U.S. Geological Survey's Invasive Species Research Center in Fort Collins, Colorado, working with several partners, has created a web-based early detection and rapid reporting database for use by volunteer groups trained to assist in identifying local invasive species. The database is publicly available to any agencies that wish to use the data and may help local mapping and response efforts.
- Effective EDRR requires strong public awareness and involvement. Many agencies have public education programs that support EDRR efforts with cross training and volunteer programs. They have increased public curiosity and awareness of the environment. For example, Bureau of Land Management (BLM) is collaborating with local Coordinated WMAs and the state of Wyoming to test the different elements of the FICMNEW EDRR plan for invasive plants. The concepts of the FICMNEW EDRR plan have been integrated into all of BLM's actions with more than 50 Coordinated WMAs in the western United States.

The Invasive Plant Atlas of New England (*IPANE*) (*62*) developed "Invasive Alerts" so that individuals can watch for additional incursions. Each alert contains information on the occurrence, when it was first observed, and the potential threats from the invader. A regional map to show where these incursions are and photographs to facilitate identification are included. IPANE's "Rapid Responders" database is used to establish teams of experts once a new incursion has been reported.

The Invaders Database includes weed distribution records for five northwestern states, with maps, photographs, and biological information updated regularly. Also, the Western Weed Coordinating Committee distribution maps of leafy spurge (*Euphorbia esula*) and yellow starthistle (*Centaurea solstitialis*) in the western United States indicate areas where early detection and rapid response may help land managers avoid widespread infestations.

Active Detection—Surveys, Data Collection, and Storage

Active detection may be most effective when targeted to sites near invasion pathways and to sensitive ecosystems. NISC compiled the following examples of successful EDRR practices among NISC cooperating agencies (*63*):

- Because little may be known about certain new invasive species and because the correct identification of specimens is critical, National Oceanic and Atmospheric Administration (NOAA) has developed a list of more than 100 taxonomic experts who can identify specimens.
- Monitoring high-risk areas and knowing what is present before an invasive species arrived (baseline data) are essential to the early detection of new invasions. Aquatic Nuisance Species Task Force members have instituted systematic monitoring programs for aquatic invasive species in San Francisco Bay, Puget Sound, the Lower Columbia River, Prince William Sound, Honolulu Harbor, Mobile Bay, Chesapeake Bay, and Massachusetts Bay. This provides baseline surveys of aquatic organisms that occur in those systems as well as looks for new invasions.

Although DOTs more often depend on chance sightings for early detection of invasive species, experts recommend that early detection of nonindigenous species be based on a system of regular surveys to find newly established species (*64*). In general, surveys for early detection are designated and targeted to answer specific questions quickly and economically, and give a "yes" or "no" answer. There are three general types of surveys to consider:

- General surveys for large or conspicuous animals and plants may be conducted by means of a "looking survey." While doing other work, staff should be vigilant and continually aware of possible signs of new invaders. The public should be encouraged to report new sightings as well.
- Site-specific surveys can be characterized as general surveys targeted at key sites; for example, high-value biodiversity areas and areas near high-risk entry points.
- Species-specific surveys where specific threats are identified and prioritized. Frequency and timing of surveys is important. The potential range of newly arrived invaders needs to be considered, along with the climate of the region. Survey methods for specific invasive plants will depend on how easy it is to recognize the target. If there are similar noninvasive and/or indigenous species present, then field guides, illustrations, and training may be necessary.

Recommended practices for surveying include:

- Recordkeeping of the species found, both native and introduced, and the action taken.

- Collection and preservation of specimens. When local knowledge is not adequate to make an authoritative identification, material should be sent for specialist identification. Local and regional museums are a good starting point for advice on identification of invasives.
- Storage of information in a database, in a standard format.

DOTs may want to establish and keep up-to-date a contact list for their specific state or region, including the names of both institutions and individuals, what types of invasive species they might be able to identify, and the methods that should be used for the specimen collection. Records of NEPA evaluations should be collected in a standard format so that they form a baseline for further use by the DOT and/or other agencies. Information about incorporating volunteers into early detection and monitoring programs may be found in *The Early Detectives: How to Use Volunteers Against Invasive Species, Case Studies of Volunteer Early Detection Programs in the U.S.* (*65*).

Effective Rapid Response

A crucial part of early detection is a contingency plan, which determines the action to be taken when an invasive species is found. Contingency plans targeted at specific high-risk species can be very efficient, providing an exact schedule for what to do. Response cannot be rapid if elaborate steps are required between detection and actual attempts at containment or eradication. Therefore, the following recommendations were derived from a national examination of rapid response approaches (*18*):

- The process for assessment and decision making should be flexible and simple, and involve detailed agreements worked out carefully in advance. This allows partners to focus on the actual response rather than on negotiating in an atmosphere of confusion and ambiguity. Agreements may be numerous and involve many levels of a hierarchical system and multiple agencies. They specify what will be done by whom in any given situation, how leadership will be identified, how funding will be arranged, and what preparation will be undertaken. Agreements should be made at the lowest appropriate levels (*18*). If flexibility in organizational structure is desired, it can be added after the preplanned organization is in operation.
- Identify an organizational structure for response in advance, but appoint individuals to positions as appropriate to the situation while organizing the response. In interagency responses, a system for assigning leaders of response organizations (Incident Commanders) could be identified through agreements made in advance. The Incident Command System could be adopted as a standard organizational model for rapid response and considered also for long-term, interagency control projects.

Early Detection and Rapid Response Findings for Federal Programs and Oversight Agencies

Research on the most effective EDRR systems nationally also found that

> federal programs that are successful include more than financial support. Simply disbursing funds and attempting to control states and localities with them is not likely to be successful in the long run. Provision of logistical and scientific support and quality leadership engenders a close working relationship and a spirit of federal–state cooperation.

Areas where scientific expertise is likely to be useful to states are (*18*):

- Identification and systematics;
- Techniques for surveillance, detection, monitoring, and related data analyses;
- Eradication and control technology; and
- Biology/ecology with emphasis on risk assessments.

These areas of expertise are needed in each taxonomic group or type of invasive species. NISC's research also found that the quality of detection and response activities may be enhanced by providing training and certification in detection and response (*18*).

Over a 5-year period, FICMNEW developed a Conceptual Design for a National EDRR System for Invasive Plants, after deciding that EDRR is the most cost-effective and environmentally sound approach to addressing invasive species. The proposed National EDRR System for Invasive Plants has five elements: (1) Detection and Reporting, (2) Identification and Vouchering, (3) Rapid Assessment, (4) Planning, and (5) Rapid Response (*66*). To facilitate these elements, the effort plans to develop and identify lists of target species, listserves, and contacts for reporting, and develop generic (broadly applicable) rapid response protocols and action procedures for use by local, state, tribal, and regional partners. These generic rapid response plans are to be provided in various invasive plant websites and publications. They plan to include basic protocols for detection and delimiting survey data to be collected during treatment efforts and methods for post-treatment appraisal surveys. The initiative also plans to develop and provide technical expertise on rapid response methods and procedures through the development of a cadre of scientists and technical specialists to provide on-site and distant support on rapid response initiatives and developing, modifying, or adapting web-based, computer-assisted, decision support systems to aid land managers in identifying and developing management options and priorities for addressing new invasive plants. The effort also seeks to collaborate with state and national partners to develop, test, and implement post-response monitoring protocols and establish a mechanism for reporting post-management monitoring results and an alert network if more action is needed (adaptive management feedback loop).

State Department of Transportation Early Detection and Rapid Response Efforts

Thirteen DOTs (33% of respondents) have implemented rapid responses to discovered locations or patches of invasive species. Subsets of these have developed EDRR programs. In Illinois and Maryland, District Landscape Architects notify the local maintenance yard, which responds as soon as it is able. State agriculture department staff also contacts the DOT when infestations are observed. TxDOT uses rapid response statewide and the WSDOT's EDRR use an e-mail list of field staff.

DOTs are more likely to employ EDRR for species that are new to the state to eliminate and avoid new burgeoning problems (Nevada, New Hampshire, and Oregon DOTs). EDRR is also used when a big push is on for elimination or reduction of priority species. For example, Mn/DOT is attempting to eradicate common reed and Grecian foxglove (*Digitalis lanata*) from the ROWs; early detection and rapid response are employed to "hold the line" on weed spread into new counties or to prevent it from gaining a foothold in new segments of highway.

California DOT (Caltrans) and FHWA have partnered to address exploding populations of the Sahara Mustard plant in the Mojave and Sonora deserts, where highway corridors have been blamed for the weed's spread. FHWA was instrumental in gathering federal and state partners to work with Caltrans as part of a rapid response effort and in funding a workshop. Caltrans is inventorying the plant on the ROW, which will be used as a benchmark for subsequent control (B. Harper-Lore, personal communication, Aug. 18, 2005).

STATEWIDE INVENTORY OF INVASIVE OR NOXIOUS SPECIES IN RIGHT-OF-WAY AND UPDATE OF DATABASES

Twenty-eight percent of responding state DOTs (11 states) have undertaken a statewide inventory of at least one invasive species in the ROW. Four state DOTs (10% of respondents) have one currently in process and five states (13% of respondents) plan to implement one in the future. Nearly one-third of responding DOTs reported that they do not plan to implement a statewide survey in the future (see Figure 3).

Although statewide tracking of invasive species is relatively uncommon, the Maryland State Highway Administration tracks the location and quantities of certain invasive species on ROWs statewide. In particular, the agency is trying to achieve and document a 25% reduction in Canada thistle in the ROW by 2008. Tree of heaven (*Ailanthus altissima*) has also been targeted. Mn/DOT is working on a research initiative with the University of Minnesota to develop a statistically valid weed sampling system to determine weed extent and whether the agency is gaining or losing ground. In 2006, Montana (MDT) is completing a noxious weed inventory of all

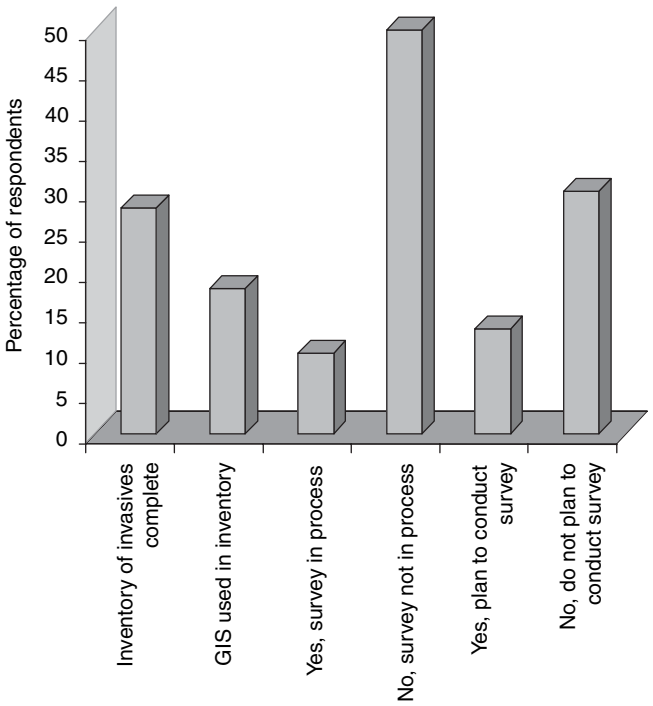

FIGURE 3 Inventory and surveys.

roadsides. NYSDOT has developed an extensive electronic inventory with control information for the APIPP, which is then used in annual meetings with partners to evaluate and continuously improve treatment efforts, adjust plans, and ensure accountability, as necessary. Counties are increasing in sophistication as well. Some New York counties are maintaining GIS data for tracking and controlling infestations of priority invasives. Colorado and North Carolina DOTs have used GPS to map and track larger problem sites. Ohio DOT is exploring combining its endangered plant inventory program with an invasive plant inventory. WSDOT maintains area IVM plans, with treatments tracked in an associated database.

A number of state transportation agencies, including the Louisiana Department of Transportation and Development (LADOTD), Mn/DOT, and NYSDOT, have been tracking and evaluating control of particular invasives over smaller areas (i.e., not statewide), sometimes using GPS units with sub-meter accuracy (Minnesota). Although statewide surveys have not been undertaken in Arizona, within the maintenance division, the Arizona DOT has been using the annual level of service surveys to map invasive species within ROWs. Maintenance staff uses that information in management and work planning. Maintenance and construction staff takes weed awareness training to identify invasive and noxious species and control them.

Inventory Approaches and Use

State DOTs have performed inventories in a variety of ways; however, by far the most common method has been inventory

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by local maintenance yards and districts. Temporary staff and universities have been hired, and DOT office technical staff helped in a number of cases. Alabama was the only state to have a university conduct the inventory statewide, although after attempting to perform an inventory through county weed coordinators, MDT is working through Montana State University and the Agricultural College to hire temporary employees to conduct the inventory, with support from university staff. WSDOT involved counties, in that case, noxious weed boards. In almost all cases, updating of the database and GIS occurs through ongoing observation by maintenance staff.

Of those DOTs that have undertaken a survey, more than two-thirds used GPS and GIS. States using GPS to map stands of invasive species included Iowa, Kansas, Maryland, Minnesota, Missouri, New Mexico, New York, Oklahoma, Oregon, Texas, Utah, and West Virginia. Such GPS and GIS information can then be used to track treatment effectiveness (M. Venner, 2002 survey). Implementation of a mapping system is an element of the IRVM plan for Mn/DOT Maintenance Area 3B. To accomplish this, computer-sided dispatch maps were obtained from Mn/DOT and plat books were obtained from the county. The maps that were developed included established areas of noxious weed infestations, hazard trees, native seeding, and other important elements of the management plan. These maps are updated and assist in program planning, recordkeeping, and assessment. Paper-based map systems are widely being converted to GIS. *NCHRP Synthesis of Highway Practice 341* reported that Maryland and Utah have connected their IRVM plans to GIS and GPS (*67*). WSDOT is using ArcIMS (Information Management System) to track both species location and treatment effectiveness.

New York State Department of Transportation's Inventory Model

In addition to maintaining an electronic database of all priority invasive plant locations identified in association with capital project development and delivery, NYSDOT strongly encourages all transportation regions to initiate and manage an inventory of priority invasive plant species for the highway systems within their jurisdiction. NYSDOT's directions identify four species of statewide priority to include as a starting point and common basis in any inventory. Additional consideration is recommended for region-wide priority species established through participation in WMAs, APIPP, Watershed Management Plans, or similar planning efforts. For prioritization purposes, the regional inventories begin with the Interstate, expressway, and parkway systems, the primary introduction and dispersal conduits for invasive plant species. The NYSDOT calls for a similar format and compatible databases for regional inventories, with variability expected regarding the specific inventory methods and parameters included in the regional inventory. The forms NYSDOT uses for data collection and monitoring are in Appendix C. NYSDOT also has a sample database format available for sharing.

NYSDOT recommends establishment of a Regional Inventory Coordinator and a multidiscipline Regional Team. Although inventory information has been coordinated by the headquarters Environmental Analysis Bureau primarily through the regional maintenance environmental coordinators, design and construction staff are now collecting inventory information as well.

NYSDOT describes the following inventory methods in the agency's Environmental Procedure Manual (*68*):

- Collect reference marker location information and complete the Inventory Data Collection Form for manual entry into GIS project.
- In GPS "Mapping Mode," collect "Point" GPS coordinates from the center of the plant infestation and complete preprogrammed GPS data dictionary attribute information or NYSDOT Inventory Data Collection Form, for each point.
- In GPS "Mapping Mode," collect "Line" GPS "start" and "pause" coordinates for linear plant infestations or collect "Area or Polygon" coordinates for patches, complete preprogrammed GPS data dictionary or NYSDOT Inventory Data Collection Form, thus allowing GIS to map and sum the inventory information.

Collecting information in this manner facilitates entry into a Regional Invasive Species GIS Project. Each Regional Maintenance Environmental Coordinator receives electronic copies of the NYSDOT Invasive Species Inventory database and copies of the NYSDOT Inventory Data Collection Forms attached in Appendix C of this document. This information can then be used during project development as a site screening tool and provided to maintenance staff for risk assessment and planning for necessary roadside maintenance activities or for implementing additional "preemptive" invasive species controls. As these regional databases develop, NYSDOT aims to track and monitor progress of control efforts at regional and statewide levels and contribute to larger statewide and region-wide inventory programs; for example, WMAs, APIPP, and Watershed Management Plans.

Two other sample inventory methodologies that are currently in use in New York State are (1) The APIPP Methodology (www.adkinvasives.com) and (2) The Nature Conservancy Weed Information Management System (WIMS) (www.TNC.org). The APIPP methodology has been implemented in portions of 12 counties in Regions 1, 2, and 7 inside the 6.5 million acre Adirondack Park since 1999. NYSDOT's data forms are modeled closely after the APIPP forms. This inventory is conducted mutually by NYSDOT, The Nature Conservancy, APA,

and volunteers. The database is managed by the Adirondack Nature Conservancy with GIS products produced and distributed by NYSDOT. Information is collected through the use of mail-in postcards that provide the approximate location of suspected invasive plant infestations. These postcards have been distributed to NYSDOT maintenance staff and a network of volunteers. Cards are mailed to the Adirondack Nature Conservancy and staff visit the site to confirm the information and enter the data onto a field data collection form, by reference marker (blank form attached), and then into the APIPP ACCESS database. This information is next sent to NYSDOT, entered by NYSDOT into the APIPP GIS system, and a species-specific location map is produced and distributed to APIPP partners and participants. The Invasive Plant Council of New York State has promoted the use of the WIMS database as generally adopted by The Nature Conservancy as their national standard.

How Departments of Transportation Are Using Collected Information

DOT roadside invasive species inventories are all used to identify and locate areas for treatment, invasion by new species, and to set priorities. DOTs also indicated that inventories are being used to:

- Partner with other agencies in providing funding for control of specific species (California),
- Estimate expansion of weed presence (Alabama and Montana) and monitor treatment results and acres infested (Alabama and Washington State),
- Guide and evaluate invasive species control efforts (California, Colorado, Florida, Indiana, and Maryland), and
- Guide effort and budgeting to meet established goals (Maryland).

Just one state had determined the rate at which weeds are spreading: Alabama DOT estimated that the acreage of cogongrass (*Imperata cylindrical*) is expanding at a rate of 20% per year within the state. NDOT was able to estimate the accuracy of an inventory contracted out by the department by checking it against maintenance spray logs from weed crews. The agency found that the inventory was 25% different (75% accurate) by the time spraying was conducted. The agency attributed this to the accuracy of the study rather than the spread of weeds during the interim. Alabama DOT is also using their database to monitor treatment results.

Maryland State Highway Administration's inventories (each September from 2002 through 2004 for phragmites and in December 2004 for Canada thistle) are being used to chart current control efforts and to provide information on how much effort needs to be put into the program to meet the goal. FDOT focuses on two priority species.

Inventory and Mapping, Monitoring, and Analysis Resources

BLM, U.S. Forest Service, U.S. Fish and Wildlife (FWS), and the Bureau of Indian Affairs conduct inventory and mapping in coordination with county and state agencies. Other resources of inventory or mapping, monitoring, and analysis of invasive species include:

- APIPP.
- Chapter 2 of the University of Northern Iowa IRVM technical manual contains a detailed discussion on how to map and inventory vegetation.
- Mapping standards from the North American Weed Management Association.
- Invasive species monitoring resources from the National Park Service, which also provides information and links on prevention and early detection, prioritization tools, databases, references and invasive species bibliographies, and much more.
- *Guidelines for Terrestrial Noxious Weed Mapping and Inventory in Idaho*.
- Information on how to document new weeds, from *Idaho's Noxious Weeds.*
- Montana Noxious Weed Survey and Mapping System—Guidelines for individuals participating in statewide mapping project.
- Introduction to Mapping Noxious Weeds in Montana.
- Map Important Weeds for A Living Inventory, part of the *War on Weeds* series from University of Nevada Extension Publications.

Remote sensing has played an increasingly important role in identifying large-scale weed infestations. Remote sensing provides information on the location, quantity, and condition of land cover, which can be compared over time. The success of remote sensing as a monitoring tool largely depends on the instrument, topography, size of infestation, timing, and the ability to distinguish target plants from the landscape. Three to five meter scale mapping and hyperspectral analysis is often necessary during the flowering season for detection of larger populations of invasive species. TxDOT has been able to identify large populations in this manner.

Protection of Native and Rare Plant Communities in Right-of-Way

A number of states are beginning to identify rare plant species in the ROW and tailor ROW management to encourage native species. Transportation agencies in California, Colorado, Delaware, Iowa, Minnesota, Missouri, New York, and Wisconsin are among those that have begun to preserve high-quality roadside remnant native habitats, Karner Blue butterfly habitat, and other sensitive habitat types (*9*). These initiatives typically have several common elements:

- Mapped information is combined from multiple agencies. Typically, the primary mapped data on known

plant locations of rare species is obtained from the state NHP. Other potential contributing agencies may include the state DNR or forest agency, FWS, BLM, U.S. Forest Service, native plant societies, DOA, knowledgeable individuals, and local counties.
- Upon completion of the initial data compilation phase, field surveys are conducted in some cases.
- Special Management Areas are set up with particular management practices.
- Maintenance forces are educated regarding the special maintenance needs of and expectations in these areas.
- Tracking of species condition and progress may occur.

MONITORING AND FOLLOW-UP

Monitoring the numbers of a pest species killed or removed is a measure of the work being done, but is not a measure of invasive species control. The success of an invasive species control project can be measured by monitoring numbers of the pest species that remain and ultimately the condition of the ecosystem they are in. Removing an invasive alien species from an ecosystem will not automatically lead to the return of the indigenous flora and fauna. Although this is often the case, removal of one alien species may simply open the way for colonization by another. Monitoring of the impact of control actions needs to be put in place, preferably starting with small-scale activities to verify the impact of control operations, and if the results are not as expected, the management plan may need to be reconsidered and adapted in light of this new knowledge.

In most cases successful eradication programs need to be accompanied by prevention measures against recolonization by the removed species, and early warning systems should be put in place to detect colonizers early. A new infestation of the successfully eradicated species can be wiped out swiftly when detected early by using the appropriate eradication method, because the knowledge of the negative impact of the invasive species and the experience in controlling the species is established and will be supported by those previously involved.

INFORMATION MANAGEMENT AND DECISION SUPPORT SYSTEMS IN EARLY DETECTION RAPID RESPONSE

Effective systems of detection and response require ready access to data. For invasive species, these needs may be most efficiently served from a central system, or at least standardization of a designated system for each group of invasives. Needs that have been addressed in the NISC's Invasive Species Management plan include (*18*):

- A database of existing and potential invasive species in the United States with current geographic information, identification details, and control information.
- A database of institutions and experts for identification and biology of invasive species in each taxonomic group.
- A database of individuals and groups to contact in case of detection, depending on geographic location, type of invasive species, and potential threat (for use by a reporting point).

The NISC is charged with establishing a coordinated, up-to-date information-sharing system that emphasizes the use of the Internet for documenting, evaluating, and monitoring impacts from invasive species on the economy, environment, and human and animal health. Although there are many sources of information concerning invasive species, incompatible database formats and other factors impede information sharing.

The NISC is currently developing an information "gateway" accessible through the Council's website at www.invasivespecies.gov. The Council plans to help develop a fully integrated Internet-based network system that eventually will support rapid and accurate discovery of data, the automatic correlation and synthesis of pertinent data from many sources, and provide a presentation of the results of data synthesis that meets the needs of users. The long-term goal is to provide accessible, accurate, referenced, up-to-date, comprehensive, and comprehensible information on invasive species that will be useful to local, state, tribal, and federal managers; scientists; policymakers; teachers; students; and others. To help ensure that stakeholder needs are met, the NISC has formed a steering committee that includes state, tribal, federal, and local governments; nongovernment organizations; the private sector; and other stakeholders. Some basic elements of this site are now in operation and work is ongoing.

Weed Information Management System

BLM developed the "WIMS" more than 10 years ago and has since built on the system in cooperation with others. BLM developed the database called Boise–Vale to capture inventory, monitoring, and control information for noxious and invasive weeds on BLM lands. BLM still uses the model of Boise–Vale, but has developed a national web-based and spatial database for the BLM to which all offices will convert once it is completed. BLM's database now incorporates information on all invasive species on BLM managed lands; however, its primary purpose is to collect weed data. Because it is considered public domain, The Nature Conservancy has taken the database and improved its components. The database on which The Nature Conservancy, BLM, FWS National Refuge System, U.S. Geological Survey National Institute of Invasive Species Science (Oregon), and the California Department of Food and Agriculture collaborated is free and may be used to track invasive species occurrence data, current status, and treatment information.

As currently maintained by The Nature Conservancy, WIMS is a Microsoft Access-based relational database application that is designed to assist natural resource managers in managing their weed data. It can be used as a stand-alone database application that resides on a laptop or desktop computer or can be used in combination with a hand-held unit to collect field data. WIMS keeps track of three types of data records: weed occurrences (GPS point locations), assessments (size and status of the weed infestation to facilitate monitoring over time), and management treatments applied to those weed infestations. Data can be easily exchanged between multiple users, exported in North American Weed Management Association standards, and written to shapefiles for mapping in any standard GIS program. A variety of reports can also be easily generated.

Field data collected with hand-held electronic data recorders can be easily downloaded into the database. WIMS can be used on a hand-held unit (either MS Windows-based Pocket PC or Trimble) with a GPS unit to capture data in the field. When using WIMS on a hand-held unit with an ArcPad interface, a site manager can use background imagery and other GIS layers for mapping weeds, then upload the new data into the Access database automatically.

Utah Department of Transportation's ROADVEG Geographic Information System

UDOT's vegetation management professionals use the ROADVEG system, a GIS, to inventory invasive plants along with other transportation-related data. UDOT staff can track the spread of invasive plant species, monitor the progress of mitigation strategies, and query and display various vegetational attributes as needed. To date, approximately 1,360 linear miles of Utah roadways have been field-assessed and scored. As funding becomes available, the remainder of the state's major roadways will be inventoried. Utah State University assisted in the road and county land inventory process.

Pennsylvania Department of Transportation's Roadside Spray Application

Pennsylvania DOT (PennDOT) has developed a Roadside Spray Application (RoSA) system, a web-based GIS application developed with Microsoft's .NET. RoSA assists PennDOT district roadside spray specialists with collecting, storing, and reviewing herbicide spray activity along state highways. The output data from this application will serve as a status report for the districts, state, and outside agencies (e.g., DOA, EPA). The system was developed to relieve district roadside specialists from having to tally by hand results and sums and develop summary spraying reports. System users include PennDOT central office and districts, counties, and outside contractors. The system allows PennDOT's statewide roadside manager to oversee all roadside activities more effectively, including cost and production figures.

According to PennDOT's vegetation manager, Joe Demko

> RoSA is taking the department's spray information from the file cabinet to the 21st century of GIS mapping and database reporting . . . The development of RoSA has been an exciting and worthwhile experience which will allow our local maintenance operations to inquiry and map spray information in minutes from their computers.

Users input data on the location of the spraying, the type and amount of chemicals used, the contract and date, weather conditions, the applicator of the spray mixture, and material and resource costs. The system enables map views of new and historical spray data, and easier data collection, storage, and retrieval (see Figure 4). Counties and districts are also using the system to reorder chemicals based on usage figures.

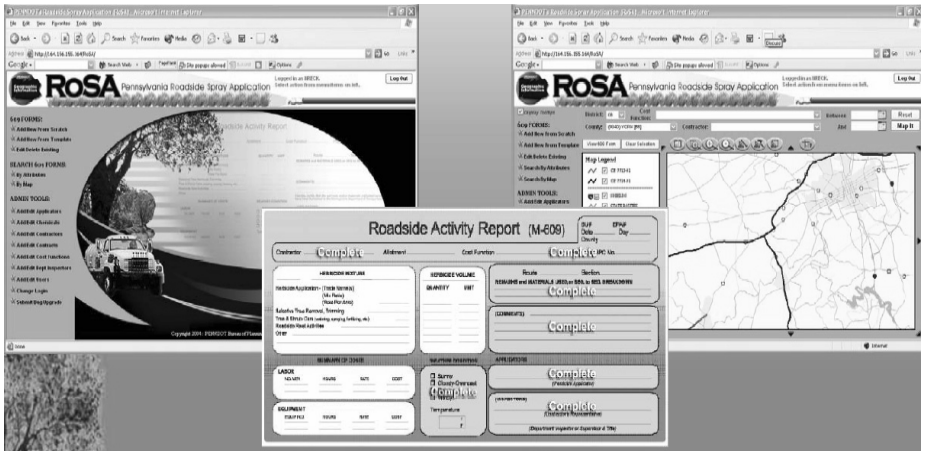

FIGURE 4 Roadside spray application (RoSA) on the web.

California Department of Transportation's Geographic Information System for Locating Appropriate Plant Species

Caltrans is developing a GIS to help employees quickly access lists of plant species for revegetation that are both ecologically appropriate for the project site and potentially useful in minimizing erosion from roadcuts and roadsides. The GIS uses hydrologic units of CALWATER at 1:24,000 as a means to link physiographic and climatological data together with the presence or absence of selected plant species in each hydrologic unit. Plant climate classifications are being refined using elevation contours and topographic aspects derived from digital elevation models to allow for assignment of different plant climates to portions of hydrologic units that exhibit steep elevational gains or considerable landform diversity. Through the overlay of other data depicting county boundaries, roads, and places, users are able to locate project sites, query the plant species climate matrix, and export data tables to spreadsheets or reports. Guidebooks that index the same plant species climate matrix through a standard "route + county + mile/km" georeferencing system make these data available to district personnel in another format as well (*69*).

Caltrans is also developing an ROW inventory system, which will include all resources in the ROW, "from stop signs to salamanders." One-foot-resolution aerial photography will allow prediction of species most likely to be there. Caltrans and the University of California–Davis plan to do resource and land use modeling to generate a variety of useful information, from the viability of wildlife crossings to the presence of different natural communities (G. Erikson, personal communications, Sep. 2005 and Jan. 2006).

Oregon Department of Transportation's Geographic Information System-Based Sensitive Resource Inventory

ODOT has developed a GIS-based inventory of sensitive resources and erosion control problem areas along nearly 6,000 mi of state highway as part of its Salmon Resources and Sensitive Area Mapping Project. The primary purpose of the project is to provide accurate resource protection maps to roadway maintenance crews so that mowing, pesticide application, and other activities do not harm listed salmon species and other sensitive resources, and that streams and banks in poor condition might begin to be addressed.

The comprehensive resource inventory was developed by using color infrared digital imagery with 2-ft resolution. Other sensitive resource features were recorded from current knowledge bases and limited roadside surveying and from modeling of interactions between multiple resources and data layers. After distance to water, stream, and bank characteristics, known threatened and endangered species locations and the overall condition of the salmon and trout habitats were identified. ODOT compared the imagery to previous data collected from other sources, such as wetland information from the National Wetland Inventory and hydrographic data from the U.S. Geological Survey, to update and validate these findings.

GIS maps were tied into ODOT's linear referencing system, which enables the agency to identify the locations of sensitive natural resources features within one-hundredth of a mile (*70*). From this GIS resource, ODOT's Transportation Inventory and Mapping Unit and the Information Systems Branch developed a series of detailed resource maps in 0.01-mi segments, which indicate where sensitive resources are present, including which side of the road. Based on the potential for environmental harm, certain restrictions were developed for each mile of highway. This information was then placed on restricted activity zone maps, which were designed to alert ODOT staff to specific locations of sensitive natural resource features to avoid inadvertently harming wildlife or wetlands when performing routine maintenance practices, such as slope maintenance, snow removal, and vegetation management. They also served to help minimize the potential for violations of the Federal Endangered Species Act and the Clean Water Act. ODOT supplied these maps to all districts for use by biologists, planners, and maintenance managers. Laminated Restricted Activity Zone Maps for maintenance use a simple color-coding scheme of green and red to indicate, for each major class of maintenance activity (e.g., surface and shoulder work, vegetation management, snow and ice removal), whether or not that activity should be restricted along the left or right side of a given 0.01-mi segment of highway.

For approximately the same cost as field surveys, ODOT produced better quality data that were less subject to individual interpretation and covered a much larger analysis area—1,000 ft from the roadway centerline, without concern for access and trespass issues. By using remote sensing techniques to collect and map data, ODOT recognized significant savings, both in cost and time.

The library of GIS data resulting from the project has given ODOT's regional staff a detailed environmental inventory of ecological resources, facilitating consideration of sensitive natural resource features when planning and designing transportation system improvements. The maps have proven to be a reliable, desktop scoping tool. The GIS system, data layers, and existing modeling routines facilitate easy updating as new information and aerial photography becomes available. ODOT is now developing an Internet-based application to enable wider desktop access to the information. Because the inventory data are digital and easily transferable between agencies, ODOT can also easily share these data and streamline communication processes

with the National Marine Fisheries Service, the Oregon Department of Fish and Wildlife, FWS, and the U.S. Army Corps of Engineers. ODOT's Resource and Restricted Activity Zone Maps were also key to negotiation of programmatic consultation for maintenance operation activities with the National Marine Fisheries Service (now NOAA Fisheries), under the federal Endangered Species Act. Specifically, ODOT received an exemption under 4(d) of the Endangered Species Act, allowing crews to perform routine road maintenance without having to consult with NOAA Fisheries on individual actions. ODOT is also exploring real-time GPS connection to maintenance vehicles, as well as herbicide application spray booms to automatically activate and deactivate applicators as needed to avoid affecting sensitive resources including streams, wetlands, or rare plant populations.

New York State Department of Transportation's Plant Database

NYSDOT's plant database is updated annually with occurrences mapped in GIS for four base species and additional ones in some regions. Detailed information on more species is being collected by volunteers and partners within the Adirondack Park. Sites are prioritized for management and updated manually. A field coordinator performs quality control for the system. NYSDOT is incorporating invasive species inventory with National Pollutant Discharge Elimination System outfall mapping, herbicide recertification and application, and other ongoing departmental activities. NYSDOT's database is available for sharing with other DOTs by contacting the agency. Information collection forms for the database are included in this report in Appendix C.

CHAPTER FOUR

ROADSIDE CONTROL METHODS AND RESOURCES

GATHERING INFORMATION ABOUT CONTROL OPTIONS

A successful control strategy for an invasive often begins with checking on-line and other data sources about management options for the target species. Successful methods used under similar conditions; that is, in similar habitats and climates, are preferred. Because invasions and the effectiveness of control methods vary with local conditions, general statements about suitable control methods should be approached with caution. Experience-based reports of methods used to control certain species and their effectiveness under specific environmental factors are essential for invasive species management. DOTs may benefit from using shared databases or having common points of contact on the Internet, to share and benefit from each other's experience and learning. Invasives management can greatly benefit by use of the best practices available and dissemination of experience and information.

General Versus Species-Specific Control Methods

The most successful invasive species control has been achieved with species-specific methods, which also have the least impact on nontarget species. In some instances, such as highly degraded habitats without any native species remaining, a more general method is acceptable. In these cases, a broad-spectrum herbicide, or bulldozing the ground, has limited negative effects on native biodiversity. However, in less disturbed areas; for example, in particular nature reserves, the use of a species-specific method is highly recommended.

Although DOTs strive to avoid reaching unacceptable levels of unintended consequences, impacts on nontarget species may be expected while carrying out such control measures. When control or eradication is successful, the reduced impact of the alien species on the native biodiversity normally outweighs the cost; native species that suffer losses during the control efforts typically rebound following the removal of the invasive species.

In choosing a management strategy, DOTs usually consider:

- Legal requirements related to management of invasive species and particular regulations on herbicide usage, including those in health and safety legislation.
- Best methods that have been used for this target species.
- The types of herbicides, baits, and equipment that are readily available and the ways by which further supplies can be obtained.

Plant control may involve manual methods (e.g., hand-pulling, cutting, mowing, bulldozing, and girdling), herbicides, release of biological control agents, controlled use of grazing or browsing animals, prescribed fires, flooding, planting competitive native species, and other land management practices. Land invertebrate control may involve traps (e.g., light traps, pitfall traps, and pheromone traps), mechanical and physical means (e.g., hand-picking, removal, and destruction of host species), insecticides, biological control (e.g., fungi, other insects), and other specialized means (e.g., mass release of sterile males). Land vertebrate control may involve trapping, shooting, baiting, biological control, contraceptives, or sterilization. Control of pathogens often focuses on hosts rather than measures directly orientated against the pathogen species. In some cases the hosts are eliminated—this is a preferred choice when the hosts are nonindigenous as well—in others, including diseases of humans and domesticated animals, the hosts are vaccinated. Resistance of the host can also be induced or intensified. If vectors are a part of the pathogen's life cycle, vector management should be considered. Control of marine bioinvasions is more difficult, although pathogens, pesticides, and hand-picking have been used.

Prevention is generally considered the principle defense against marine invasive species, which are distributed by one principal pathway, the ship. Organisms in freshwater habitats can be controlled with mechanical, chemical, and biological measures and habitat management. Aquatic weeds can be harvested when floating on the surface, pulled out when rooted, or sprayed with herbicides. Biological control has been particularly effective against several water weeds in different parts of the world. For example, weevils have been used to control water lettuce in the United States and other countries. Fish-specific poison has been used in the eradication of several fish invasions. Another control option for fish is recreational or industrial fishing. Mosquito larvae and pathogens vectored, and by extrapolation other freshwater insects, can be controlled by spraying chemicals or biological pesticides onto the infested water. The community of a freshwater system can be influenced by changes in the water quality and quantity in favor of native species (*71*).

Biological, cultural, physical, and chemical control methods can be used to contain and eradicate invasives.

Biological weed control includes the use of insects or pathogens.

- Physical control of invasive plant species includes tilling, mowing, and burning areas to control invasives.
- Mechanical methods include hand-pulling and mowing, which can be effective in conjunction with other control methods.
- Chemical control of invasive species relies on herbicides and pesticides.
- Cultural control of invasives includes planting native grasses or competing plant species to force out invasive species.

No individual method will control invasive species in a single treatment; diligence and persistence are often required over a number of years to bring infestations under control. In most cases, the best practice to manage an invasive species may involve a system of integrated management tailored for the species and the location. Thus, it is important to accumulate the available information, assess all potential methods, and use the best method or combination of methods to achieve the target level of control. These methods are usually combined in strategic planning to control invasives or in IVM or IRVM planning, as discussed in the previous chapter. All methods should include follow-up monitoring, treatments, and revegetation to prevent new infestations or resurgence of the target weed.

All control methods, with the exception of classical biological control, which is self-sustaining, need long-term funding and commitment. However, initial investments in developing biological control are large—usually more than US $1 million. If the funding ceases, the population and the corresponding negative impacts will normally increase, in some cases leading to irreversible damage. Successful control may be easiest to achieve in areas of lower density of the invasive species. The degree of success will vary with different organisms, the ecosystem, the duration of the effort, the restoration effort, etc., and the optimum management strategies are location-specific and must be tested and fine-tuned for different areas.

Control of nonindigenous invasive species aims for the long-term reduction in density and abundance to below an acceptable threshold. If prevention methods have failed and eradication is not feasible, managers will have to live with the introduced species and can only try to mitigate the negative impacts on biodiversity and ecosystems. In the short-term, because control appears to be a cheaper option than eradication, it is often the preferred method. Funding and commitment do not need to be at such high levels as for eradication programs, and funding can be varied from year to year depending on the perceived importance of the problem, political pressure, and public awareness.

The DOT makes a decision to consider harm caused by the species under this threshold as acceptable with regard to maintenance objectives, costs, damage to biodiversity, and economy. Suppression of the invasive population below that threshold can tip the balance in favor of native competing species. The weakened state of the invasive species allows native species to regain ground and even further diminish the abundance of the alien species. In rare cases this might even lead to extinction of the nonindigenous species (especially combined with habitat restoration efforts to support native species and put intact natural systems back in place); however, this is not the principle goal of control efforts (*71*).

TAILORING TREATMENTS TO DEPARTMENT OF TRANSPORTATION FUNCTIONS AND DEVELOPMENT STAGES

NYSDOT has tailored invasive species control procedures and methods to DOT functional areas and stages in the transportation planning, development, construction, and management processes. A number of these practices are described in the section on prevention in chapter three. For example, all NYSDOT capital projects and appropriate maintenance activities and roadside operations shall consider and address, as practical, the potential environmental effects of invasive species. This process and analysis includes, at a minimum: (1) an inventory of the project area, (2) consideration of potential environmental impacts, and (3) incorporation of appropriate preventive measures and control practices into project documents and activities.

BIOLOGICAL CONTROL OF INVASIVE SPECIES

Biological control is the intentional use of populations of specialized organisms, commonly referred to as natural enemies, against pest species to suppress pest populations. It involves introducing herbivores, parasites, predators, or pathogenic microorganisms to suppress a target plant or animal pest. Biocontrol agents are living organisms that have specific requirements for growing and thriving. Understanding the life cycle, habitat requirements, and mode of attack assists in finding a hospitable release site and allowing the user to integrate the biocontrols into other control efforts.

Different Types of Biological Controls

The aim of biological control is not to eradicate targets. In a successful biological control program, the invasive species' population will be reduced to an acceptable level, but populations of prey or host and natural enemies will remain present in a dynamic balance. Biological control can be successful in all habitat types and is often the only alternative for use in nature reserves and other conservation areas because of its environmental-friendly nature and the prohibition of pesticide use in many such areas.

As described by the Global Invasive Species Programme, biological controls may be categorized as follows (*72*):

- Pheromone traps, based on chemicals produced by the target species to attract other members of the same species, are species- or genus-specific in most cases, and allow the selective collection of the target species. Occasionally species may be controlled effectively by using high densities of traps, particularly in a small or restricted area. Therefore, if the pheromone is readily and cheaply available in large amounts, the release of high doses can interfere with mate location and mating. If the air is filled with the pheromone the insects are not able to detect and find a partner. This method is only feasible for small infestations. Generally, pheromone traps are more effective when used to monitor the presence or abundance of a species. For instance, traps can be used for early detection of high-risk species. This may enable a rapid response action to attempt eradication or containment. Traps can also be used to monitor the density of pest species, so that when the catches reach a certain threshold other control measures are triggered. The progress of an eradication program can also be followed by monitoring the density (and later the lack) of the target species.
- Biopesticides—These are biological pesticides based on beneficial insect and weed pathogens and entomopathogenic (i.e., insect-killing) nematodes. Pathogens used as biopesticides include fungi, bacteria, viruses, and protozoa. Produced, formulated, and applied in appropriate ways, such biopesticides can provide ecological and effective solutions to pest problems. Most product development to date has been directed toward control of pests having direct economic impact, particularly for the control of pests of agriculture, forestry, and horticulture (caterpillars, locusts, various beetles, and weeds), and medical and nuisance pests (mosquitoes, blackflies, and flies). Most types of biopesticides are relatively specific to their target pests, and many are very specific. It is this specificity that makes their use attractive compared with broad-spectrum chemical pesticides. The most widely available and used biopesticides are various formulations of *Bacillus thuringiensis*, which can be used to control the larval stages of Lepidoptera (caterpillars), and selected Coleoptera (beetles) and Diptera (e.g., mosquitoes and flies).
- Entomopathogenic nematodes—These are increasingly available in specialized niche markets, such as horticulture, and are used to kill selected invertebrate pest targets.
- Fungi—For control of specific weeds (mycoherbicides or bioherbicides) various types of fungi have been available for some time, and the development of new ones is increasingly routine (see e.g., the International Bioherbicide Group website at http://ibg.ba.cnr.it/). These products are usually host-specific either as a result of the physiology of the fungus or because of the way they are used. This makes their use attractive in many situations, but also means that the market is small, making them commercially less attractive than traditional herbicides. Nevertheless, a niche market exists and could be developed to address specific conservation needs to control invasive alien plants, as part of a management program. For example, the development and use of mycoherbicide products to be used for stump painting in the control of plants such as *Rhododendron ponticum* in Europe is under consideration. Fungi for control of insects is also a relatively new research area; however, products are now coming onto the market, notably Green Muscle, a formulation of *Metarhizium anisopliae* for control of locusts and acridid grasshoppers (*73*).
- Pathogens for control of vertebrates—Not only can pathogens be used as biopesticides but there are also opportunities to use them against vertebrates. Unlike more traditional interventionist techniques, a disease might spread with little human assistance and remain effective for years. Potential pathogens must be carefully screened for risks to other animals and humans. Thus, pathogens, such as chemical insecticides require significant preliminary testing and verification before use.
- Biological control of freshwater and marine targets—The opportunity to use biological control against plants, invertebrates, and vertebrates was described earlier. To date, no biological control project has been attempted against a marine invader, although studies on the suitability of several parasites against different organisms are underway; for example, specific parasitic castrators of crabs.
- Biological control of plant diseases—This is still a young science. Many plant pathogens colonize parts of the plant that are initially free of microorganisms. Successful biological control in such circumstances depends on rapidly colonizing these plant areas with nonpathogenic antagonists competing for the space. The principal antagonists used are saprotrophic fungi and antibiotic-producing bacteria. The biological control agent will ideally outcompete the pathogen. This concept is altogether a rather different approach than the biological control projects against weeds, invertebrates, and vertebrates. In some cases, less virulent strains of the same pathogen species can be used to replace the virulent strain physically or by transmission of the traits of the less virulent strain to the virulent one.

As used today biocontrols are a relatively inexpensive and safe alternative to chemical or mechanical control. Some of the introductions made more than 100 years ago were of generalist predators, including vertebrates such as mongooses and cane toads, and these did have severe adverse affects on nontarget populations, including species of conservation importance. Such species would not be used today in biological control, and some of them are good examples of invasive alien species causing serious

problems. However, today the safety standards of biological control for invasive plants are very rigorous. It is a normal requirement [e.g., International Plant Protection Convention (IPPC) Code of Conduct] to assess the specificity of all agents proposed for introduction. This involves extensive laboratory and field screening tests. An informed decision can then be made by the appropriate national authority taking into consideration the potential for any effects on nontarget organisms. In the United States, petitions for release of herbivorous biocontrol agents are reviewed by the Technical Advisory Group (TAG), which makes recommendations, whereas USDA, APHIS, and state regulatory authorities are responsible for issuing permits for importation, testing, and field release of biological control agents of weeds.

Biological control can be divided into several approaches grouped under two headings: those that are self-sustaining and those that are not. Methods that are not self-sustaining (which all target insect pests) include:

- Mass release of sterile males to swamp the population with males that mate with females without producing any offspring in the next generation.
- Inducing host resistance against the pest. This approach is particularly relevant to agriculture where plant breeders select (or create) varieties resistant to diseases and insects.
- Biological chemicals; that is, chemicals synthesized by living organisms. This category overlaps with chemical control and whether to list a particular method in one or the other category is a question of definition; for example, while applying living *Bacillus thuringiensis* (known as "BT") is without doubt a biological control option; to which group the use of the toxins stored in the organism belong could be debatable. Other examples of chemicals in this group are rotenone, neem, and pyrethrum, extracted from plants.
- Inundative biological control using pathogens, parasitoids, or predators that will not reproduce and survive effectively in the ecosystem. Large-scale or mass releases of natural enemies are made to react quickly to control a pest population.

Self-sustaining biological controls include:

- Classical biological control, which at its simplest is the introduction of natural enemies from the original range of the target species into new areas where the pest is invasive. Invasive alien species are often controlled in their indigenous range by their natural enemies, but are usually introduced into new environments without these natural enemies. Freed of their natural enemies, alien species often grow and/or reproduce more vigorously in the area of introduction. Natural enemies for introduction are selected on the basis of their host specificity to minimize or eliminate any risk of effects on nontarget species. The aim is not the eradication of the invasive alien, but to reduce its competitiveness with native species; hence reducing its density and its impact on the environment.
- Augmentation of enemies under pest outbreak conditions for an immediate control, when the enemy can reproduce in the new environment. The control agent is reared or cultured in large numbers and released.
- Habitat management can enhance populations of native predators and parasitoids; for example, the release or replanting of native alternate hosts and food resources.

The most important of these is classical biological control. Conservation managers are beginning to realize that this method, if used following modern protocols such as the IPPC's *Code of Conduct for the Import and Release of Exotic Biological Control Agents* (*74*), provides the safest and most cost-efficient approach to solving many invasive alien species problems.

Biocontrol is typically a long-term, environmentally acceptable approach for the control of a target plant species. In comparison with other methods, classical biological control is, when successful, highly cost-effective, permanent, and self-sustaining. It is ecologically safe owing to the high specificity of the agents used. The main disadvantages are the lack of certainty about the level of control that will be achieved and the delays until the established agents achieve their full impact. Biocontrol agents can take 5 to 10 years to become established and increase to numbers large enough to achieve control. However, with a potentially very positive benefit–cost ratio, the benefits of classical biological control normally outweigh the drawbacks and it represents the cheapest and safest option to date. Such a long-term control method is best initiated in low-priority areas, at sites where the use of other control strategies would be cost-prohibitive. Once control agents build high enough populations and spread easily, control methods with shorter effect times can be replaced by biological control. A major problem is that there are many noxious plant species for which biocontrol agents are not available at the present time.

Department of Transportation Biological Control Activities

Almost one-third (13 state DOTs) of respondents are using biological controls to some extent. Biocontrols also have played a particular role in some DOTs in places where there is no operational need to control, such as some wetlands or where the area is inaccessible.

Several DOTs have become very active in the use of biological controls. *NCHRP Synthesis of Highway Practice 341* on IRVM reports that biological control practices using herbivorous organisms such as beetles and seed flies are in use

on 0.5% to 2% of the ROWs in Florida, Illinois, Kentucky, Maryland, Utah, and Washington (*67*). Other examples include the following:

- Caltrans has research underway on biological controls for yellow starthistle and tumbleweed (Russian thistle, *Salsola tragus*) (*75*).
- NYSDOT and other DOTs use *Hylobius* sp. and *Galrucella* spp. beetles on large, dense stands of purple loosestrife (one-half acre or larger). Cornell University conducted extensive research before the selection of these particular species and prepared a generic EIS for its release throughout the state. These beetles feed exclusively on purple loosestrife (they will starve rather than eat any other plants), will reproduce after release, and can be harvested from prior release sites for use in other locations. Research is currently underway by Cornell University to identify and test effective biological controls for introduced common reed (*Phragmites australis*), garlic mustard (*Alliaria petiolata*), water chestnut (*Trapa natans*), and Japanese knotweed (*Fallopia japonica*).
- In 1995, Mn/DOT launched its first school partnership in beetle rearing for roadside use, an educational and public awareness success story, after two beetle species released at a site in southern Ontario effectively reduced purple loosestrife infestation by more than 90% over 5 years, allowing native plant populations to extend their reach (L. Skinner, Minnesota DNR Coordinator, Purple Loosestrife Program). The Mn/DOT Office of Environmental Services uses beetles to control leafy spurge (*72*).
- Between 1997 and 1999, New Hampshire DOT and the Department of Agriculture (NHDA) monitored a beetle release at a mitigation site infested with purple loosestrife. By 2000, all loosestrife within and adjacent to the site was either dead or extremely stressed and dying, and none of the remaining live plants appeared to develop flowers and therefore seed. Self-sustaining populations of beetles were still found among the remaining loosestrife plants. Indigenous vegetation, likely from seed in the existing soil bank, filled the void and restored diversity. New Hampshire DOT and NHDA released beetles at 12 additional sites the following year (*76*).
- Michigan State University's laboratory produces 150,000 beetles per year, which the Michigan DNR has been releasing on state game areas infested with purple loosestrife since 1994. The lab has trained local groups around the state to rear the beetles, and release and monitor their effect, leading to an expected 80% reduction in density in 10 to 20 years.
- The Vermont Agency of Natural Resources and Vermont Agency of Transportation (VTrans) have mapped purple loosestrife populations and VTrans is testing three approaches: (1) the release of beetles without mowing or spraying; (2) mowing right after flowering begins for easy identification, yet not be mature enough to disperse seed; and (3) spraying (*76*).
- Spotted and diffuse knap invasives can be controlled using one of 12 insect species cleared by USDA for use in the United States. In Tennessee, the DOT was able to reduce musk thistle (*Carduus nutans*) infestations by 95% with a biocontrol beetle (*9*).

Biocontrol Resources on the Internet

Information on biocontrols for various weeds can be found in Biological Control of Weeds in the West—Bibliography or at commercial weed biocontrol insectaries. Cornell's Invasive Plant website on Biological Control of Non-Indigenous Species is dedicated to promoting and educating people about the biological control of nonindigenous plant species and the site lists plant species where biological controls are available for eastern North America.

The Global Invasive Species Programme suggests the following sites:

- IPPC Code of Conduct for the Import and Release of Biological Control Agents (1996).
- Biocontrol News and Information.
- The Nearctic Regional Section of the International Organization for Biological Control's Biological Control of Weeds Working Group.

Other resources include the U.S. Army Corps of Engineers Noxious and Nuisance Plant Management Information System that covers:

- General Introduction to Biocontrol.
- General Concepts of Biocontrol and History of Biocontrol.
- Benefits/Disadvantages to Biocontrol.
- Process of Biocontrol.
- Overall Herbivore Effects.
- Using Biocontrol Agents More Actively in Existing Control Programs.
- Specific Organism/Damage Descriptions: Overview of Collection Techniques.
- Descriptions of the Included Organisms and Their Associated Damage.

Other web resources include:

- USDA's National Biological Control Institute.
- Biological Control Virtual Information Center.
- 110 Years of Federal Biological Control Research—USDA.
- Biological Control of Non-Indigenous Plant Species—Cornell University.
- Weed-Feeders Table of Contents—Cornell University.
- Biological Control: A Guide to Natural Enemies in North America—Cornell University.
- Biological Control: Important Tool for Managing Invasive Species—USDA.

- Biological Control of Invasive Plants in the Eastern United States—USDA Forest Service.
- Biocontrol of Forest Weeds, University of Hawai`i at Manoa.
- Western Rangeland Weeds Home → Management and Prevention → Methods of Weed Control → Biological Control of Weeds.
- Agricultural permits for weeds and biological control agents—APHIS.
- Biocontrol: Integrated strategies for sustainable control—Canada.
- Biological Control—BLM.
- Biological Control Agents by Target Weed—Oregon DOA.
- Biological Control Program—Who We Are; Biological Control Program Facility Locations from the California Department of Food and Agriculture.
- Technical Advisory Group for Biological Control Agents of Weeds—An independent voluntary committee formed to provide advice to researchers. TAG members now review petitions for biological control of weeds and provide an exchange of views, information, and advice to researchers and those in APHIS responsible for issuing permits for importation, testing, and field release of biological control agents of weeds (from APHIS).
- Cornell has set up a website with monitoring protocols for biological control of purple loosestrife, as well as protocols for garlic mustard (*Alliaria petiolata*), protocols for water chestnut (*Trapa natans*), and Phragmites (*Phragmites australis*) insect surveys. The final goal is to establish a database where results from different regions can be collected, stored, and made available through http://www.invasiveplants.net.

MECHANICAL CONTROLS

Mechanical control methods involve directly removing individual plant or animal invasives, either as a means for eradication in small areas or as a means for controlling species density and abundance. It encompasses tractor mowing and can involve anything from complete tillage for reseeding to hand scythes, shovels, string trimmers, push mowers, pruning shears, etc., for weed control and desirable vegetation maintenance. Mechanical eradication methods can be effective when the population of the invader is still small and is limited to a small area. Weeds that grow vigorously from cut plant parts or multiply vegetatively are more difficult to control. The downside of mechanical methods is the labor requirements. Most manual work is expensive and has to be repeated. Plant parts of some species left in contact with soil may survive and grow. For example, Japanese knotweed, an invasive alien in Europe and North America, will regenerate from stem cuttings and rhizome fragments of less than 1 g.

In many cases, introduced pests can be controlled or even eradicated in small-scale infestations by mechanical control; for example, hand-pulling weeds or hand-picking animals. An advanced method of mechanical control is the removal of plants by specifically designed tools and even machines, such as harvesting vehicles for water hyacinth-infested lakes and rivers. In some cases of very persistent plants growing on large open areas such as pastures, bulldozing may be necessary (*77*).

Invasive plants can be cut or hand-pulled (see http://tncweeds.ucdavis.edu/tools.html for some simple tools) and larger plants can be uprooted with the aid of tools such as winches, if necessary. The effectiveness of this technique will vary considerably depending on the response of the weed. If there is no information available about the plant's response to uprooting, some simple tests should be carried out to discover its effectiveness and ways to treat the residues; for example, composting or burning the uprooted material. Repeated cutting of a woody weed may eventually drain the resources stored in the root system and kill the plant. In many cases, combined cutting of the plant and painting the stem with a systemic herbicide proves to be more efficient. Specialized cutting tools that will apply a pesticide as they cut have been tested. Mowing of herbs and grasses may lead to the same result, when the plants are not adapted to heavy grazing. Annuals are especially susceptible if mown shortly before setting flowers, because they will have used up most of their root reserves to produce the buds. Girdling can kill trees; cutting with a knife through the cambium of a tree trunk and removing 5 cm of bark will interrupt the flow of nutrients and kill the plant. Girdling alone may not suffice for rapidly killing those species where the water and nutrient movement are not restricted to the outermost layer of the trunk; however, an application of herbicide will speed up the process.

Regarding fauna, control of most insect species depends on traps, which are more or less specific to insect groups or species-specific using pheromones. Sedentary species such as scale insects or mealy bugs can be killed by destroying their food plants. Trapping and shooting can be considered the "mechanical" or "manual" way of dealing with invasive vertebrates. Recreational hunting of game can be effective in keeping populations down to an acceptable level and can be a revenue source for other management activities in the area. It does, however, give rise to the concern that the invasive species then becomes a valuable commodity that should be preserved to continue to generate this income. Furthermore, there are many instances where recreational hunting will not reduce the target population sufficiently. Similarly, recreational hunting can be counterproductive as a result of amateur hunters creating a shy target population and not being skilled enough to reduce target species desired densities. Also, depending on the species, recreational hunters may select only mature trophy males as targets; this will have little or no impact on the reproductive capacity of the species. To reach the predetermined target population level, it may be necessary to

employ professional hunters. Using animals such as dogs, which can be specifically trained to target individual invasive species, can be extremely successful in combination with shooting and other forms of control.

Fencing is another option for containment of species, either cordoning off the species in a certain area or fencing off ecologically valuable land. One needs to be sure that the invasive species is not present on both sides of the fence.

Mowing

Maintenance roadside mowing, while essential for safety, operational, aesthetic, and environmental purposes, can, has, and does play a significant role in the introduction, spread, and proliferation of invasive plants. Mowing can serve as a control method for certain invasives during certain periods of their reproductive cycles, but repeated mowing and attention to timing will be required. Mowing is most effectively used in combination with other vegetation management and invasive species control techniques. Few studies have been conducted on the effects of mowing plant communities and invasive species.

Just 30% of responding state DOTs reported that they are timing mowing to control invasive species. Slightly fewer (25%) say they will mow in some areas to minimize seed transfer.

Reduced mowing practices were initiated as early as the 1950s. The Wisconsin DOT (WisDOT) was a pioneer in the cutbacks. Many more DOTs reduced mowing in the 1970s, when high energy costs forced vegetation managers to mow less and spot spray, with the positive consequence of increased wildlife habitat, enhanced natural beauty, minimized herbicide use, reduced maintenance dollars, and public acceptance (*9*). *NCHRP Synthesis of Highway Practice 341* noted that state DOTs remain heavily dependent on mechanical control methods, with the bulk of states cutting more than 90% of their ROW, a smaller set having reduced mowing to 50% to 90%, and only Florida and Washington indicating less than 50% was managed using mechanical methods (*67*).

Mowing should be carefully considered to ensure that the target species will not actually be spread by the practice. Because mowing cuts the tops of plants, more buds may grow, producing more stems than before; however, continuous mowing when plant reserves are low can gradually deplete root reserves. If flower-feeding biocontrols are used, weeds can still be mowed at times when natural enemies are not feeding. One of the greatest advantages of mowing is the ability to quickly reduce seed production.

Because drainage ditches, streams, and wetlands can rapidly spread invasive plants through the dispersal of seeds and, to a lesser degree, plant parts, it is strongly recommended to control (herbicide, excavate, etc.) priority invasive plant populations in and adjacent to drainage ditches and streams, before mowing. This also will provide operational benefits, because invasive plant populations in the drainage system that are "only" mowed will immediately regrow and spread and therefore require additional mowing. Isolated (upland) roadside populations of invasive plants can be mowed with less chance of dispersing the plant seeds and parts to new areas. Nevertheless, mowing should always be done before seed maturation, which typically occurs later in the last half of the summer.

Because mechanical mowing spreads invasive plant seeds and each segment of many invasive plants, including the rootstock, can vegetatively sprout a new plant, priority invasive plant species should be mowed with due consideration for the following factors (*78*):

- When mowing untreated or uncontrolled invasive plant populations, do so before seed maturation.
- Plan on mowing invasive plant populations two to three times per year, before seed maturation, for successive years, if mowing is the only control practice used. The "mowing only" option should be used in locations that are not in or adjacent to drainage ditches and are inaccessible or too large for other control options.
- Control small invasive plant populations comprised of tender, young plants with herbicide early in the summer, before mowing, especially in and adjacent to drainage ditches.
- If invasive plant populations consist of large, mature plants, mow the plants before seed maturation, allow the plants to regrow to a height of 2 to 4 ft and then treat the area with foliar herbicide, especially in or adjacent to drainage ditches.
- Physically remove flower or seed heads (cut and bag) of small invasive plant populations before mowing, especially in and adjacent to drainage ditches.
- Physically remove the rootstock (mechanically excavate) of small invasive plant populations before mowing, especially in and adjacent to drainage ditches.
- Control large purple loosestrife plant populations with biocontrol beetles (*Hylobias* sp. or *Galrucella* spp.) before mowing. Beetle releases will take several years to significantly reduce purple loosestrife populations.
- If mowing occurs after seed maturation, hand clean, with brush or broom, the upper parts of contaminated mowing equipment before moving to new locations—especially uncontaminated locations. This is especially important for purple loosestrife, because each mature plant is capable of producing up to 2.5 million viable seeds.
- Take care to minimize scalping and rutting during mowing operations. These situations can be avoided by properly adjusting the equipment and avoiding operating

equipment directly in wet areas or rough terrain. Any scalped or rutted areas should be immediately seeded and mulched. Any badly rutted areas should be repaired, seeded, and mulched.
- Use of optional mowing equipment, such as "over-the-rail" boom-type mowers, may be necessary in some situations to reach invasive plants.

The Montana State University Extension Service has compiled a number of recommendations on mowing to manage invasive species, which are summarized in many of the upcoming sections (*79*).

Identify Targets and Communicate with Relevant Parties

When mowing to reduce invasive species, recommended practices include:

- Identifying invasive species that can and should be controlled by mowing (at least in part), identifying the location of patches, and determining thresholds when mowing should occur for these areas (such as when patch area exceeds a certain size).
- Identifying invasive species that should not be mowed or conditions under which they should not be mowed to avoid inadvertently spreading these invasives.
- Communicating with other maintenance staff to avoid mowing areas soon after or just before spraying, and to avoid mowing areas of leafy spurge and other species that spread with mowing.

Time Mowing to Suppress Invasive Species

Properly timed mowing can suppress some invasive species while favoring desired methods if used in conjunction with other methods. Timing is based primarily on the growth stage of the plants to be mowed and secondarily on the growth stage of the desired plants. If desired vegetation cover is inadequate (usually less than 20%), revegetation is likely to be necessary.

Some desired plants, such as grasses, have equal amounts of growth above and below ground. When grasses are defoliated during the growing season, this stress reduces vigor and the ability to maintain competitiveness, and to allow grasses to produce seed for next year's stand it is best to mow when these plants are dormant. Caution should be exercised, because mowing during the weeds' seeding period can facilitate seed dispersal.

Establish Mowing Frequency

Mowing frequency for invasive species control should depend on precipitation and the mowing tolerances of the vegetational function of relative growth rates, leaf replacement potential, and the plant's ability to increase photosynthesis after mowing to compensate for leaf loss. Particularly important are the number, location, and source of growing points on plant stems. An effective mowing strategy minimizes the removal of growing points of desired plants and maximizes removal of growing points of weeds.

For annual, biennial, and taprooted perennials the frequency of mowing depends primarily on precipitation. A single midsummer mowing after flower production can reduce or eliminate seed production and shift the balance in favor of desired species in areas with little or no summer rain. In one study, 78% control of diffuse knapweed (*Centaurea diffusa*) was achieved after mowing to a 2-in. height each month during the growing season (no mention of revegetation context). However, as summer rains increase, regrowth potential increases, and mowing may increase plant vigor and seed production similar to pruning. In this case, additional mowing is necessary.

Rhizomatous weeds usually require more frequent mowing. Repeated mowing is considered an effective control of rhizomatous weeds in alfalfa and many pastures. In one study, mowing alfalfa two times per year reduced Canada thistle 86% after one year and 100% after 4 years. In other studies, mowing three or four times per year nearly eliminated Canada thistle within 3 years. Other studies have suggested that mowing Canada thistle kept stands in check but did not eliminate the weed.

Mowing of large infestations is a long-term commitment. Some weeds, such as those that spread through rhizomes (a prostrate stem growing beneath the soil surface) have large energy storage capacities. During the first few years, mowing these weeds can stimulate shoot production from root buds and increase stem densities. However, over time, frequent mowing at each early flowering stage can affect underground reserves and eventually reduce stem densities. In addition to Canada thistle, rhizomatous invasive species include Dalmatian toadflax (*Linaria dalmatica*), leafy spurge, ox-eye daisy (*Chrysanthemum leucanthemum*), Russian knapweed (*Acroptilon repens*), and whitetop or hoary cress (*Cardaria draba*).

Set Mower Height

Most grasses can tolerate short mowings once dormant. If the dominant vegetation has not yet shifted to invasive species and still contains adequate grass cover, mowing should generally be timed so the weeds are at the flowering stage and the grasses are dormant. When the dominant vegetation is a noxious weed, MDT recommends mowing 2 in. high when the weed is at the flowering stage. However, in some cases, invasive species will reach the appropriate stage for mowing, but the grasses have not reached dormancy. If so, MDT recommends mowing the weeds at a height above the desired plants.

Mowing above the height of actively growing grasses allows seed production and unrestricted growth; this maintains the vigor needed to minimize reinvasion. Defoliating the weeds reduces seed production and vigor, increasing resources available for neighboring grasses.

Spotted Knapweed: A Case Study

Montana State University performed a study on the effectiveness and timing of 15 different mowing strategies for spotted knapweed, showing that mowing can greatly reduce or diminish seed production and adult spotted knapweed density. The mower was set at 10 in. height to cut the bolted knapweed plants while passing over the grasses. The study found that the most effective time to mow spotted knapweed was during the flowering stage. Mowing at this time decreased adult density by approximately 85%. Seedling density also was slightly reduced. Grasses were only decreased by the most aggressive mowing treatments.

Integrating Mowing with Other Management Methods

Although mowing will not eradicate invasive species, it can stress them, greatly reduce seed production, and help give native plants a competitive edge. The pervasiveness and complexity of invasive species, combined with their cost of control, makes an integrated management plan necessary, because an IVM strategy seeks to use the most economic, ecologic, and environmentally effective combination of principles, practices, technologies, and systems to meet noxious weed management goals and objectives. Although little research has been conducted on incorporating mowing into an integrated plan, experience provides some practical hints. Some evidence suggests that combining mowing with herbicides can enhance perennial weed control. For example, mowing two or three times a year consistently enhanced Canada thistle control following applications of picloram, picloram + 2,4-D, clopyralid + 2,4-D, and dicamba (*79*). Mowing may also be combined with herbicides over several years. Most invasive species grow low to the ground after long-term repeated mowing. In these cases, periodic control through herbicides can remove plants that have adopted their growth form to frequent mowing.

Department of Transportation Mowing Policies and Programs

Eleven state DOTs have developed conservation mowing and spraying programs to protect native communities, minimize maintenance costs, and control invasives. NYSDOT's conservation mowing program is among the most well known. North Carolina DOT (NCDOT) has developed a Clear Zone Improvement Program (C-ZIP) initiative, which relies on native grasses and forbs. Fourteen state DOTs (35% of respondents) have employed reduced mowing widths (one-mower width) as a statewide standard to control costs and preserve native communities. TxDOT is among those that have marked many areas as "no mow" to facilitate their return to native vegetation.

A few states, such as Alaska and Vermont, noted that their roadsides consist primarily of native vegetation. Alaska Department of Transportation and Public Facilities indicated that the agency sometimes specifies just adding fertilizer and allowing the site to naturally revegetate. More information about DOT mowing practices may be found in the *Guide to Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance* (*80*) available at AASHTO's Center for Environmental Excellence. A selection of these practices, with invasive species control components, is included here.

Alabama Department of Transportation Mowing Program to Reduce Cogongrass

In Alabama, mowing is restricted in cogongrass areas during seed head production, mowing is to progress from areas without cogongrass infestations into areas with cogongrass infestations, and mowers are to be cleaned of all vegetative propagules before leaving cogongrass-infested areas.

North Carolina Department of Transportation Mowing Program Modifications to Encourage Wildlife Native and Rare Plant Species

NCDOT implements its mowing program with an environmental perspective to encourage wildflowers, protect rare or endangered plants and protect or create wildlife nesting areas. Currently, NCDOT protects more than 35 populations of rare plant species growing along its roadsides. Endangered plant populations are marked with white-topped wooden stakes, an indication to mowers that the area is off-limits during the growing season. These areas are managed on a site-by-site basis according to their individual needs. Management strategies to control invasive woody vegetation include mowing during the dormant season, hand pruning, and prescribed fire. NCDOT cooperates with the North Carolina Wildlife Commission in posting and managing small game wildlife habitat areas in the ROW. Properly timed cleanup mowings enhance wildlife habitat (*81*).

New York State Department of Transportation Stewardship Mowing Practices

General NYSDOT mowing guidelines are outlined in the agency's *Mowing Limits Manual*, Highway Maintenance Subdivision Operational Guidelines, and *Environmental Handbook for Transportation Operations*. The *Mowing Limits Manual* addresses safety, water quality and erosion, sedimentation control, appearance and screening, landscape plantings and woody vegetation, and natural revegetation.

NYSDOT's *Environmental Handbook for Transportation Operations* outlines stewardship practices and expectations for mowing, which go beyond mowing reduction policies to address other environmental features in the ROW (*82*).

In addition, NYSDOT is implementing Conservation Alternative Mowing Plans (CAMPs), which preserve safety and aesthetics while reducing invasive species and enhancing native habitat. CAMPs involve identification of rich landscapes as part of the maintenance planning process, threshold values for several species and suitable habitat in the landscape, species or groups of species to be used as indicators, and the barrier effect of roads (*83*). CAMPs have been successfully developed and implemented on Interstates, expressways, and parkways at NYSDOT through a multidisciplinary team approach, culminating in the following guidelines, using four zones that describe to the operators what management is expected in the different zones. A High Management Zone is comprised of an intensely managed area immediately adjacent to shoulder or curb, a Frequently Mowed Zone next to it is mowed multiple times per year, an Annually Mowed Zone provides a transition between the Frequently Mowed Zone and No-Mow Zone (or left to regenerate naturally), and a No-Mow Zone is left in its natural state or left to regenerate naturally.

Mowing Management in Southern Quebec, Canada

According to a study commissioned by the Ministère des Transports du Quèbec, traditional methods of controlling vegetation along the agency's 2000 km of highway corridors in southern Quebec "result in a boring landscape, deteriorate the various wildlife habitats, and impoverish wild plant life while generating high maintenance costs." Recently, the agency has pursued the development of new maintenance methods, including elimination of multiple annual mowings, to improve the safety of the highway system's users, satisfy neighboring residents, beautify the landscape, and consider the plant life and wildlife present along the highways. The new approach eliminates multiple mowings except on the first 2 m from the pavement, which will be mowed more frequently to ensure highway safety (visibility) and better control of the allergen, ragweed. The agency and its researchers have also been monitoring the slowly increasing biodiversity in the unmowed area since 1998 (*84*).

Manual Removal—Pulling Weeds and Seed Head Cutting

Pulling weeds by hand is practical and efficient on small, isolated patches of weeds. It has the advantages of low damage to other plants and minimal equipment cost. Hand-pulling is most effective on annuals and biennials that do not resprout from root fragments. The labor requirements often make hand-pulling impractical, but because perennial weeds can resprout from extensive root systems, hand-pulling has the potential to be ineffective as well.

- Pull plants when soils are moist and before seeds are produced to prevent additional spread of the weed.
- Try to remove the entire root system, because many weeds can resprout from remaining root fragments.
- Attempt to keep soil disturbance to a minimum.
- Ten DOTs (25% of respondents) said they used hand-picking of weeds in some areas. NYSDOT has done manual cutting of seed heads with bagging and disposal where further control is not possible.

Tilling and Disking

Tilling and disking mechanically removes weeds from the soil, slices through roots, or buries weeds. It is fast and effective against a wide variety of weeds; however, it can only be used in crops, pastures, and some rangeland. It can also lead to loss of soil moisture, increased soil erosion, and mixing of seeds into soil, a potential problem because it is not usually followed by residual control. Tilling does not kill most perennial weeds, but deep tillage of taprooted plants in late fall can expose roots to deadly winter frosts and interfere with the translocation of nutrients to roots for storage. In many areas the disturbance caused by cultivation creates a niche for new weeds to become established.

Cutting and Brushing

Cutting is used primarily for woody plants. It minimizes soil disturbance and involves tools such as brush cutters, power saws, axes, machetes, hand-pruning tools, loppers, and clippers. Smaller shrubs can be cut with power mowers, string cutters, machetes, scythes, or weed whips. When plants are cut, roots remain intact and are helpful in stabilizing soil on steep terrain. To minimize resprouting, stems should be cut close to the ground under maximum drought conditions.

The effectiveness of cutting largely depends on the plant species, stem diameter, time of cut, and age of the plant. For example, scotch broom's ability to resprout declines with age. Cutting broom to the ground during dry months (usually after flowering) usually kills the plant, whereas cutting before flowering, although effective in preventing another seed crop, may result in resprouts and little mortality.

Cleaning Mowing, Cutting, and Removal Equipment

Equipment used for invasive species control, whether hand tools or power driven, should be cleaned before entering a new site and before leaving the site, to reduce transport of plant propagules and the potential for new invasive introductions. This is particularly important for some invasives that produce millions of seeds.

PHYSICAL METHODS

Physical methods of invasive species control include covering, burning, grazing, and changing abiotic factors.

Covering

Covering plants deprives them of the sunlight needed for growth and hastens plant decomposition by contact with soil microbes. Less cover is used (mulching) when trying to foster new germination.

- Materials used to cover plants should block all light. Common materials include thick black plastic, black geotextile fabric, and mulches. Black geotextile mats are often used under highways, as landfill lining, and in landscaping projects.
- Before covering, cut, burn, or mow the weed close to the ground to reduce biomass and to put stress on the plants. Treatment sites require regular monitoring to detect and repair torn fabric.

Although covering can be very useful, it has several drawbacks. Unless the material is biodegradable, the cover must be removed after the treatment. In addition, the amount of time needed to kill weeds varies and will need to be experimentally determined.

Caltrans is testing two types of solid mats—Durotrim, a 1-in.-thick black matting made of recycled rubber tires, and Weedender, a light-green product made of recycled plastic bottles that is approximately 1/4-in.-thick, and a liquid soil sealer called Polypavement, which binds to the soil making it impervious to plant growth and erosion. The product from recycled plastic bottles is so light that it requires workers to secure it to guardrails. Although Caltrans has used all the products before, the test is the first time the agency has applied the weed control products simultaneously in one area for a side-by-side comparison of effectiveness with no herbicide use. Caltrans District Five is experimenting with the use of native grasses and organic materials, such as wood chip mulch and corn gluten meal, to test their effectiveness in mitigating the growth of invasive weed species. The tests are also assessing community response to the look of the products, ease of application, and cost relative to herbicide application. According to Caltrans project management, other potential benefits that may be realized by the test include (*85*):

- Minimizing traffic congestion by eliminating lane closures associated with more traditional vegetation control activities.
- Enhancing worker safety by reducing the frequency of on-site work on the highways.
- Minimizing fire concerns by eliminating vegetation overgrowth.
- Improving drainage by removing weeds around drainage facilities.
- Promoting visibility of traffic, highway structures, and wildlife.
- Reducing the need for herbicides.

Controlled Burns

Eight percent of DOTs are using controlled burns to restrict invasive species and foster native revegetation. Controlled burning or prescribed fire is a carefully planned and controlled fire conducted to manage natural areas such as prairie, oak savanna, wetlands, and oak woodlands. Prescribed or controlled burns have been used by land managers for more than 25 years in modern history and for hundreds of years by Native American tribes. The fire kills the above-ground parts of shrubs and small trees.

In certain environments the practice of prescribed burning can change the vegetation cover in favor of native plant species, thereby decreasing population levels of weeds. Prescribed burning is particularly appropriate for restoring or maintaining fire-adapted or fire-dependent species and natural communities. Many invasive plants are not adapted to fire and ecological burning may be an effective tool for controlling these species.

Fire has been used quite frequently to manage invasive alien species in the United States and to stimulate natural vegetation in areas adapted to fire. For example, The Nature Conservancy has used controlled burns to eradicate Australian pine (*Casuarina equisetifolia*) in pine forests and other fire-tolerant communities in the United States, but less frequently elsewhere. Spot treatment is also possible; for example, early in the growing season baby's-breath (*Gypsophila paniculata*) can be burned with a hand-held propane torch. Prairie plants grow more vigorously when built-up plant materials and shade are removed. Spring fire uncovers the soil, warming it sooner and extending the growing season. Roadside areas across the United States are the site of important remnant native grassland habitats, many of which can be enhanced by management by fire. Many invasive plants are not adapted to fire; therefore, ecological burning may be an effective tool for controlling these species. However, land managers must first determine if fire is a natural component in the plant community in question and if prescribed fire can be expected to help meet site goals.

The context should be carefully evaluated to avoid notable failures and so that desirable species may be promoted rather than invasive species. For example, an Australian study of roadside burning noted that non-native plants were spread into adjacent woodland and that native species decreased (*86*). It should be remembered that the growth of some invasive alien plants, such as garlic mustard in woodlands of the northeastern United States is stimulated by fire. In other areas, fires can cause disturbance and create establishment sites for new weed infestations.

Only trained and experienced people should undertake prescribed burning owing to the many health and safety risks involved. Smaller infestations can be controlled with the aid of a flamethrower. The risks of a large-scale fire limit the use of these tools, especially in dry climates. Given these ecological and logistical challenges, prescribed burning may not be an appropriate method if considered for invasive species control only. It is best suited to a site where restoration and maintenance of fire-dependent or fire-tolerant communities are primary conservation goals.

Controlled Burn Practices and Consideration

Fire intensity, continuity, and duration are factors to consider in the success of a treatment. Controlled burning offers the following benefits (*72*):

- Controls invasives and woody invaders,
- Stimulates the growth of many native prairie plants,
- Removes thatch,
- Recycles nutrients, and
- Warms the soil and gives warm season plants an earlier start.

After two growing seasons, planted prairies need to be burned annually for the next several years to become well-established (mature prairies with no serious weed problems may need burning only once every 2 to 4 years) (*87*). Recommended practices include the following:

- Always use caution when burning.
- Check local fire and air quality regulations and obtain permits.
- Try to burn or mow only one-third of the prairie area each year to preserve over-wintering insects, their eggs, and pupae.
- Always plan fire safety into plantings, even if you are not going to use burn management. Prairie fires intentionally or accidentally set during fall or spring dormancy can burn very rapidly.
- Use any existing features such as roads, driveways, streams, lakes, or mowed lawns as fire breaks.
- In addition to paths through a prairie, also include a wide path around the perimeter.
- A mowed lawn buffer 20 ft in width between buildings and prairie is advised.
- An alternative to burning is to mow in late fall after seeds set or preferably in early spring (late March to mid-April). Sites that are too wet in spring need fall mowing when soil is dry.
- If burning does not occur periodically, cuttings need to be removed to avoid a thatch layer buildup.
- Do not cut and then burn large quantities of plant material (creating thick piles) or you will sterilize the soil beneath.
- Revegetation after a fire is important in reducing bare ground and preventing the establishment of other weeds.

Before undertaking a controlled burn, staff must be properly trained and plans developed. Planning considerations should include:

- Traffic safety—any burning plan must include smoke management provisions for safety purposes.
- Weather conditions.
- Equipment.
- Staffing.
- Timing—burning is most beneficial from mid-April to early May for warm season grasses.

Controlled burning is practically explained by Wayne Pauly in his *How to Manage Small Prairie Fires* (*88*). The Missouri Department of Conservation recommends the following practices for controlled burns, drawing on Pauly's work: While fire management requires training and knowledgeable individuals, it takes "as little as a few hundred dollars in equipment, including drip torches, rakes, and safety clothing. . . . Roadside prescribed burns are easy. The road is one fire break and the others can be a mowed field of harvested hay or lawns" (*89*). Staff undertaking burns should be forewarned that corn stubble and older fence posts smolder.

More detailed information on controlled burns for invasive species management may be found in the Center for Invasive Plant Management's on-line resource: "Fire as a Tool for Controlling Non-Native Invasive Plants" (*90*). The review "focuses on the intentional use of fire, alone or integrated with other methods, to control exotic plants in North America." Additional information regarding proper burning procedures can be obtained from the Fire Management and Research Program at The Nature Conservancy or state resource agency. The Texas Parks and Wildlife Department uses an on-line burn plan form for controlled burns on state property and provides a Sample Burn Plan.

Controlled Burning or Hay Removal as Roadside Grassland Management Alternatives to Mowing

Mn/DOT and the University of Minnesota have been exploring whether mowing can be as effective as yearly burning at encouraging native prairie grasses and discouraging botanical invaders. A research team investigated the effects of burning and mowing on three separate test areas, examining above-ground vegetation and below-ground fungal communities, as well as measuring changes in various soil parameters. Findings and recommendations were as follows (*91*):

- Prescribed burning has the strongest effects on plant community composition and was the most effective

method to increase above-ground plant biomass in a restored tallgrass prairie. Burning especially favors warm season grasses and legume species, although it also favors certain annual species. Also, when immediate grass cover is desired, burning is the best maintenance technique available to increase grassland productivity.

- When burning is not an option, haying may be the next best alternative. The addition of lime may be important to consider on restorations of former agricultural lands.
- Adding lime to hayed prairie may help benefit the cool season plants, native and exotic.
- Spring haying is an acceptable alternative to spring burning, although its effects are less dramatic than the burn. In particular, haying does not favor warm season grasses as extensively and may not damage cool season species as thoroughly as burning. Spring haying did not control exotic species.
- Burning and haying provided the greatest increase in arbuscular mycorrhizal fungal structures, which may correspond to the increases in plant growth on these treatments. In prairie restoration, addition of arbuscular mycorrhizal inoculum appears to provide long-term benefits.
- The effect of mowing the prairie in the spring is similar to that of no management on the plant community. It is only useful for the control of woody species. Mowing may temporarily decrease nitrogen mineralization rates. This may help to prevent invasive species, but is not likely to do so if mowed annually.
- Frequent burning or haying should be done to prevent the accumulation of inorganic soil nitrogen, which may favor many weedy species. If haying is used instead of burning soil, pH should be tested periodically to detect acidic soil, Although this did not become apparent on this experiment, it may occur on long-term hayed grasslands. Acidification may lead to decreases in certain plant populations or losses in productivity.
- The process of removing litter seems to be the most important cause of the ecosystem response to prescribed burning. Hayed plots are the most similar to burned plots in terms of soil moisture, temperature, and litter quantity. Hence, litter removal by haying will likely be a sufficient practice to replace prescribed burning at many sites.

Department of Transportation Examples of Controlled Burning for Invasive Species Management

A number of midwestern state DOTs use controlled burns. Illinois DOT attempts to use burns if the timing is right. The agency mows if burning is not an option and uses chemicals as necessary.

In California, 5 acres of highway ROW were targeted to learn more about prescribed burns as a management tool. The Bear Creek Botanical Management Area, one of the last examples of Upland Wildflower Fields in California, contained a plant community remnant with more than 200 native California plant species. After careful planning, Caltrans District 3 employees coordinated the safe passage of vehicles and the California Department of Forestry and Fire Protection conducted the burn. The key target was yellow starthistle, which had invaded half the site within a short time. Observations following the fire have shown the prescribed burn to be more effective than the preceding years of mowing, spot spraying, and hand-pulling of starthistle; however, the state is attending to air quality issues (*9*).

Infrared Treatments for Managing Invasive Species

Infrared technology uses radiant energy (heat) to kill unwanted vegetation. Intense heat generated by liquid propane coagulates plant proteins and bursts cell walls, killing seedling plants and destroying the tops of established vegetation. Repeated treatments at regular intervals deplete the root reserves of established plants and lead to their decline and eradication. In a study by ODOT, infrared treatments were applied at three rates (eight, six, and four treatments per year) along Oregon highways and compared with shoulders treated with herbicides and unmanaged control sites. Results suggested that infrared technology can keep vegetation under control on roadway shoulders; however, timing of treatments to plant growth cycles, weather, and fire conditions is critical (*92*).

Grazing

Grazing is a biological alternative to mowing and has been considered a physical method, a biocontrol method, or a habitat management method. Continual grazing of the tops of young plants can retard plant development and seed formation and can gradually deplete root reserves. Because animals might prefer to eat nearby grasses in lieu of the target weed, they may be enclosed in a fenced-off, weedy area.

This invasive species control method works best where the plants that are to be preserved are adapted to grazing; that is, they are either adapted to high populations of large herbivorous mammals or prevalent in human-made habitats such as pastures and heathland. Conversely, unmanaged grazing often favors alien plants, because grazing can preferentially remove native vegetation leaving alien plants, especially toxic species, to grow under reduced competition, leading to a monotypic stand of an alien plant.

The following are four classes of grazing management plans that can be used for weeds in general:

- Seed removal involves grazing the weed in the spring to remove the bracts and flowers, and perhaps again in

late summer. This type of grazing prevents seed set, but does little to reduce the root system.
- A multiple pasture rotational system is a properly timed, rotational grazing system that continuously defoliates the target weed throughout the growing season. This eliminates seed production and causes limited stress on the root system. It is useful when large infestations occur over many acres.
- Intensive rotational grazing involves grazing the plant in the spring until it is completely defoliated and then rotating the animals to the next pasture. In late summer each pasture is grazed a second time. This method places optimum stress on the plant, which decreases plant vigor and carbohydrate reserves.
- Continuous grazing, for approximately 4 months, allows goats or sheep to graze throughout the growing season, thus preventing weeds from recovering and maximizing stress on the root system and its reserves.

Allow animals to graze weeds only before they flower and set seed. If this is impossible, contain animals for 7 to 14 days in a holding area before moving them to noninfested areas.

Habitat management with grazing mammals can be a suitable option to obtain the desired plant cover. Goats and sheep are economical and do not pose the environmental dangers of applying chemicals. If confined, Angora and Spanish goats will trample or browse virtually any vegetation within a fenced area. Desirable trees or shrubs can be protected with light-weight flexible fencing (*93*).

Maintenance managers have "hired" goats for control of broadleafed invasive species control in California, Montana, Nevada, and New Mexico, among other places. Caltrans' Technology Transfer newsletter described several examples (*94*). In 2000, a Billings Public Utilities Department maintenance mechanic hired a pair of angora goats to munch on a particularly abundant yellow-flowered noxious weed that grows along the banks of the Yellowstone River. The goats showed a preference for the top part of the leafy green perennial where flower buds form, preventing blooming and subsequent spread. The goats continue to be used to clear around drainage facilities in Billings. It was found that goats eat whitetop, Canada thistle, spotted knapweed, leafy spurge, and bindweed. The Billings Public Utilities Department has also used the goats as part of an integrated bio-control management program in conjunction with introduction of *Aphthona lacertosa* flea beetle, which attacks the leafy spurge root systems.

In Albuquerque, approximately 1,000 goats were brought in to clean up weeds along the Rio Grande. The district biologist reported that "tightly managed and limited use of goats is a really good and ecologically sound way to manage vegetation without having to use herbicides or fossil fuel for mowers" and leave the native grasses to flourish. The state of New Mexico plans to use goats to clear more than 1,200 mi of canals, drains, and ditches, which would normally be cleared using costly electrical equipment, herbicides, and manual (human) labor. The goats provide a way to do this that is more cost-effective, saves energy, and safeguards the environment (*94*). Denver's naturalist attempted something similar, but encountered problems stemming from the sheer logistics of trying to mobilize 50 to 275 goats in an urban environment, as well as unleashed dogs that chased the goats. Nevada uses a combination of grazing with goats, careful herbicide application, mowing, and seeding with annual plants. Along the Truckee River, goats that were put out to graze on whitetop weeds infesting the floodplain ate approximately 75% of the young, tender regrowth. Such efforts have done much to control the growth and spread of weeds. In Montana, BLM found that grazing sheep controlled approximately 90% of the leafy spurge weed over a 4-year period. Without sheep, the Bureau was spending $40 to $50 per acre on herbicides for weed control; today, with the help of the sheep, there is only a need for minor spot applications of herbicides. In Wyoming the DOT estimates that sheep grazing the land costs $18.80 an acre to maintain, compared with $185 to $310 an acre using herbicide, and $350 an acre to control growth through hand-cutting and mowing (*94*).

In Rackerby, California, Goats Unlimited raises small New Zealand "Kiko" goats just for controlling weed growth. Their goats are serviced out to assist with rejuvenation, erosion control, and restoration projects, as well as creating firebreaks and clearing ditches. Goats can help an agency reduce its dependence on fossil fuels and, because goats, unlike mowers, do not start brush fires with sparks from their motors, they have been used extensively since the fires of 1990 in the Oakland–Berkeley Hills area to safely manage the growth of undesirable vegetation by clearing dense undergrowth, including the highly flammable manzanita. Numerous agencies in the Bay Area now employ the goats for vegetation control. In the Sacramento area, 350 goats are clearing an acre a day. In San Luis Obispo, flood control managers have used goats to clear drainage channels along the Arroyo Grande Creek. Goats, traditionally mountain dwellers, do well on steep terrain, which poses a challenge for workers with power mowers. Also, the goats will contentedly "work" any time of day or any day of the week. For large groups of goats, goatherds are sometimes required (*94*).

Changing Abiotic Factors

Most invasions of nonindigenous species are caused or at least favored by human disturbance of the ecosystems. In these cases, a mitigation of negative effects by the invasive species could be achieved by changes in the human behavior that has led to the invasion. An example would be a change in the quantity of nutrients and/or water available for plants, which would alter the plant community. In some cases, invasive aquatic organisms can be controlled by improving the water quality,

addressing eutrophication and pollution problems, or even changing the quantity of water; for example, draining or a water-level regime adverse for the invasive species.

Hunting and Other Use of Nonindigenous Species

Continuous hunting can be used to control exotic species, such as deer, originally introduced for hunting purposes. There are two approaches: commercial hunting principally for meat and recreational hunting.

Problems encountered trying to control an alien species through hunting usually relate to land ownership and the distribution of the invasive species. Some species spread into suburban areas where hunting is not allowed. Many groups within the human population, particularly in developed countries, find hunting morally unacceptable, and so it may decrease in popularity, thus allowing alien species formerly controlled by hunting to explode in numbers.

Many other invasive species can be eaten or have edible fruits, which can be exploited for human consumption or as fodder for domesticated animals. In many parts of the world with high human density, invasive plants are also esteemed for their production of highly valued firewood or for other uses. A high percentage of introduced fish and crustacean species are fished either recreationally or on an industrial scale.

A significant drawback of this approach as a control method is the promotion of an alien species as a food resource and the promotion of new industries depending on what otherwise might be better to eradicate. The market may provide an incentive for individuals to spread the alien species to as yet uninfested areas, or breed them in captivity, from where they may eventually escape. Thus, the costs and benefits must be evaluated on a case-by-case basis.

CHEMICAL METHODS

Herbicides adversely affect the physiological activity and development of plants and are used to control vegetation by causing death or suppressing growth. These compounds, as active ingredients, are incorporated into a wide variety of commercial herbicide formulations for application to plants and to surrounding soil or water as sprays, granules, and liquid concentrates. Herbicides can be grouped on the basis of their chemical structure and physiological action or on the timing and method of their application. Chemicals with similar structure usually produce the same type of physiological reaction in plants and control similar species. Nonselective herbicides control all vegetation because they affect physiological processes common to all plant species. Selective herbicides will damage only those groups of plants that carry the biological pathways they target.

Herbicides are the major method of invasive species control in non-crop situations as well as in agriculture because they are relatively effective, reliable, cost-efficient, safe, and easy to use. In addition, some areas virtually require treatment by herbicides; eradicating vegetation that grows around and under a standard current guardrail is very difficult without the use of herbicides. Nevertheless, human health concerns have encouraged public agencies in particular to examine and encourage alternatives to herbicide use. In the past, extensively used broad-spectrum pesticides such as DDT had massive detrimental effects on the environment as well as human health; however, today these products are banned in most countries, and there are more specific products on the market with fewer negative nontarget effects. Some insecticides, such as those based on chemical structures similar to insect hormones, can also be specific to target groups of insects.

Other major drawbacks of herbicides are the high costs, the necessity of repeating an application, and the effects on nontarget species. Repeated use of pesticides also provides the selective pressure that enables many target species to evolve increasingly effective resistance to these chemicals. In response, either the dose has to be increased or a different group of pesticides has to be used, usually further increasing the control costs. There is also the possibility that indigenous peoples will oppose the use of toxins on their land; for example, where toxins may accumulate in sublethal levels in nontarget species that may be an important food source for indigenous peoples. This latter concern is primarily true of persistent pesticides such as modern anticoagulants and the now largely obsolete organochlorine compounds.

Selection of a pesticide to control an invasive species begins with a determination of effectiveness against the target and all appropriate nontarget species that might come in contact with the chemical, either directly or through secondary sources. Additionally, the environmental half-life, method of delivery, means of reducing nontarget species contact, demonstration of efficacy, and collection of data to ensure compliance with environmentally safe use (as set out by the regulatory bodies in the country where it will be used) must be evaluated. Most countries require pesticides to be registered for specific uses. Once identified, tested, and registered, a pesticide can allow for the rapid control of a target species over large areas and, as a result, reduce the need for the personnel and costs for the traditional methods.

Widely used application methods for herbicides include treatments of the bark of young trees or application of herbicide into the wounds created by girdling or cutting. This cut-stump application method, mentioned already in the section on mechanical control, is very effective against many woody plants. Herbicide can also be applied directly to the leaves of the invasive species by using a sponge, wick, or a syringe; however, a less specific and more common method is spraying of infested areas. As a general rule, foliar herbicides are

applied to young, tender, actively growing plants before flowering. If the plants are too mature for effective herbicide application, a common practice is to mow an invasive plant infestation, before seed maturation, allow the plants to regrow to a height of 2 to 4 ft and then apply the appropriate foliar herbicide. This process can weaken the plant and prevent spreading by seed, and maximize the effectiveness of the herbicide application. Owing to the vigorous nature of many invasive plants, especially knotweed and phragmites, this process may need to be repeated two or three times over consecutive years.

Stem "cut and treat" herbicide applications involve the cutting and removal of the growing plant stems and then the spot application of herbicide to the freshly cut surface of the remaining rooted portion of the stem. The herbicide will then be translocated down into the plants' root system. The "spot" application can be accomplished with a swab or hand sprayer and should occur as soon as possible, but not more than 1 h from the time the stem is cut (within 15 min is preferred for best results). A common practice is to have one individual cut the stems while a second follows and applies the herbicide. It is important to mark which stems have been treated—using a marker dye is a common technique. This technique is recommended in situations where foliar treatments are not possible or effective, such as with Japanese knotweed. If stands of invasive plants extend beyond the ROW, a written release may be sought from the adjacent landowner to implement controls. All sites where herbicides are applied should be inspected 3 to 4 weeks post-application to assess success and to determine if natural revegetation by native or noninvasive plants is adequate or if additional restoration, for example, seeding and mulching, is required (*95*).

Insecticides can be sprayed selectively on infested plants, plant parts, or indiscriminately over a large area. Application should always be as focused on the pest as possible; for example, spraying of the attacked plant part, at the most susceptible time for the target, and limiting the use to the efficient dose to minimize side effects on other species.

Pesticides are used against vertebrates primarily in baits; for example, bait stations for rats. Before using bait, small-scale experiments and observations can be carried out to determine which nontarget species might take the bait. With some ingenuity, it may be possible to develop bait stations that give easy access to the target species but prevent, as far as possible, other species from entering it. Naturally, a more target-specific bait station is easier to design for an ecosystem with no species similar to the target species.

Chemical substances are used to mitigate diseases in humans and animals. Water and surfaces capable and suspected of disease transmission are treated with disinfectants to kill pathogens before entering their hosts.

Chemical treatment offers one of the few options for control of marine invasive species, although its potential is limited. Herbicides (e.g., glyphosate and 2,4-D) have been used extensively around the world as a quick and effective means of controlling weeds in freshwater environments. However, because they are nonselective and more difficult to apply directly to the target plant in water, they are more likely to cause harm to nontarget species. The fish poison rotenone is frequently used to control fish species in ponds and other small water bodies. This method is efficient for the eradication of species; however, the nonselective character limits its use for large-scale infestations.

DOTs are required to follow the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and other appropriates laws and mandates when using herbicides or pesticides. DOTs are required to use all herbicides in accordance with label instructions, state and federal law (including adjacent landowner notification requirements), and by or under the supervision of certified applicators.

Herbicide Use as Part of an Integrated Vegetation Management Program

Judicious use of herbicides is an important tool in invasive plant control efforts. IVM stresses the need for selectivity, restraint, and proper training and protections whenever herbicides must be used. On the road shoulder and in other zones too, invasive species must be controlled to protect against the undesirable succession of plant communities, not only for the sake of the roadside zone itself, but also to prevent the roadside from becoming a refuge for invasive species and the source of further spreading. Chemical vegetation controls are used to protect preferred vegetation, to provide fire protection, and to improve roadside appearance.

In IVM programs, herbicides are considered transition tools that enable the manager to suppress weeds and replace them with desirable, competitive vegetation. Therefore, it is important to select the least-toxic, low-residual herbicide that is effective against the target weed and to apply it in a judicious manner. The Cooperative Extension Service, state agricultural experiment stations, or County Agriculture Commissioner should be consulted for specific herbicide recommendations and information on their use in particular localities.

Responding to Public Concerns of Herbicide with Integrated Roadside Vegetation Management and Improved Stewardship Practice

DOTs find themselves in the public spotlight over herbicide use. In integrating all the IRVM tools, FHWA has outlined the following recommended steps to follow before herbicide use (*96*):

- Evaluating each site to determine if invasives really present a problem.
- Spot mowing to prevent annual weed seed production.

- Removing a [non-native species] and allowing desirable species to reclaim the area.
- Prescribing burning of prairie communities to promote healthy vegetation.
- Using biological controls as alternatives.
- Frequent roadside management equipment cleaning to help reduce seed transfer.

DOTs have also responded to public concerns with herbicide reduction and/or notification efforts (*97*).

- Caltrans pledged to decrease herbicide use by 50% between 1992 and 2000, and by 80% by 2012. District 1 governments can opt for no herbicide spraying.
- Iowa DOT controls invasives with herbicides only if mowing or other controls are not practical. Forty-one of 99 counties in the state participate in IRVM programs.
- NYSDOT set up a toll-free number for members of the public to find out about spraying plans.
- North Carolina, Oregon, and Washington State DOTs use IVM and offer no-spray agreements to adjacent landowners. WSDOT tracks and reports on reductions in herbicide usage.

Reducing Herbicide Application and Cost with Innovative Sprayers

A number of DOTs have been active in developing the best technology for roadside vegetation control. Herbicide spraying helps eliminate unwanted vegetation; however, typically, 80% to 90% of the sprayed chemical misses its mark and is wasted, according to horticultural scientists at North Carolina State University. Recent research and development work by Purdue University led to the commercial production of an equipment system that can electronically identify individual invasives within its path and deliver a prescribed targeted application of herbicide in a single pass over the roadside. Treatment of various invasives often requires the use of different herbicides. Sprayers must have the capacity to spray more than one chemical at a time, negotiate rough terrain, and apply herbicides safely and in a way that preserves the environment. Purdue's technology and the other following examples reduce the amount of herbicide needed and DOT costs (*98*):

- Iowa's Clinton County oversees a commercial roadway management system that uses a sprayer-mounted computer connected to a GPS receiver to record the placement of multiple herbicides. The county's objective is to integrate data from years of mapping to target necessary spraying and avoid sensitive areas.
- Small sensors can be used on trucks or other equipment to pinpoint the location of an undesirable plant and then target and spray the weed with herbicide. Each sensor views a 12-in.-wide area. The unit will spray only weeds and not bare ground. Several Caltrans districts are using the sensors. A side-mounted strip of sensors at the rear of a vehicle lets the unit target and spray roadside weeds at 10 mph. Using the sensors cuts herbicide amounts and costs by 50% to 80% compared with broadcast or manual spot spraying. The sensors have their own light source so they can be used at night when traffic is light. Units with the sensors need only the driver, reducing work hours required as well.
- At North Carolina State University, Drs. Jim Burton and Walter Skroch developed an herbicide applicator that can be attached to weed mowers. The unit applies a film of chemicals to the weed stem as the plant is cut by the mower. From 70% to 90% of the herbicide is absorbed into the plant to prevent future growth. The applicator, called the Burch Wet Blade, is designed for use on rotary roadside weed cutters. A reservoir mounted on the cutter's deck holds the premixed chemical solution. A pump regulates an adjustable flow of the chemical through the spindle shaft and out along the blade to an opening on the cutting edge. "When you cut the plant, its vascular system sucks in the herbicide and sends it plantwide," Burton says. The system is a closed one that never sprays into the open air, which is safer for the operator.

Mn/DOT tested four sprayer designs, each of which saved money compared with traditional sprayer use, according to a report by Claudius Toussaint, Mn/DOT Office of Maintenance Operations Research. Savings of up to $65,000 per sprayer were cited (*99*).

- The B & B Ditch Sprayer 300 prototype contains a 300-gal. oval-shaped plastic tank and a sprayer equipped with two spray booms, each consisting of drop nozzles and providing a 60 ft spray pattern. The spray boom has an innovative spring-loaded feature. Although this system had the lowest net savings of the four tested sprayers, it offered a rate of return of 360%.
- The Wanner Innovative Sprayer system includes an 850-gal. stainless-steel tank, with spray material dispensed from the tank and delivered to the spray nozzles by means of a pumping system. Spray booms consist of drop nozzles and end-mounted boom-buster roadside nozzles. Additionally, there is a single straight stream nozzle mounted on the end of the boom. The system is also equipped with drop nozzles, which are used for spraying road shoulders. All spray nozzles are remotely controlled from the truck cab. The Wanner sprayer is more economical for use in large districts or in areas with extensive road miles, owing to its capability for applying herbicides at high speeds and accurate amounts. The large size of the supply tank is also a factor in the sprayer's ability to service large areas. The rate of return was measured at 76%.
- The Micro-Track Spray System, a multiple-injection spray system with console monitors, can be connected to any size of supply tank. The system is capable of spraying up to five different herbicides simultaneously, and the supply tank, chemical tanks, pumps, monitors,

and nozzles are all mounted on one unit. No trailers are needed. The Micro-Track sprayer had the highest rate of return, 1,142%.
- The SCS 750 can independently control the liquid, granular dispensing systems, and overall hydraulic system at the same time. If spot spraying is needed, each chemical can be controlled by a manual switch. Hand-spraying attachments are also available for spot spraying. The spray rate is controlled by a wheel-driven speed sensor. Visual and audible alarms alert the operator to any deviation from the programmed rate of application. Measurements can be calculated using the metric or U.S. measurement systems. Calibrations and weather information are stored in the 10-year memory capacity. A compact printer is plugged into the 750 console to obtain a readout of the daily activities. The SCS 750 sprayer had the highest net annual savings along with the advantage of being able to monitor, tabulate, and print out all vital statistics (areas, dosages, weather conditions, application rates, and so on).

Washington State Department of Transportation Efforts to Minimize Herbicide Use Through Integrated Roadside Vegetation Management

As a single government body, DOTs are often the largest users of herbicides in the state and therefore have drawn criticism for this from environmental groups. WSDOT's strategy for dealing with the public concern regarding herbicide use has been to implement IRVM through the agency's local crews at the field level, increase the accountability of the program, and minimize herbicide use over time by working to establish desirable, low-maintenance plant communities that will naturally preclude the establishment of undesirable plant species. WSDOT is developing roadside vegetation management plans for each of its 24 maintenance areas. As of 2005, WSDOT had developed and implemented such plans for approximately one-third of the state's 7,000-centerline-mile system. Complete coverage is scheduled by 2007. In dealing with the most sensitive and controversial areas to date, WSDOT's IRVM approach has incorporated the following:

- Planning—development of an IRVM plan that contains an inventory of roadside management features and provides specific documentation on how WSDOT will treat various aspects of the roadside.
- Communications—meetings and ongoing dialogue with interested individuals, groups, local governments, tribes, and neighboring landowners to discuss, negotiate, and decide on specific roadside vegetation management policy and practice.
- Research—commitments to conduct research to seek out and analyze alternatives to herbicide use where they exist, through both design and construction and maintenance.
- Partnerships—inclusion of local volunteers in research, planting and roadside restoration, and weed control projects. Also, working with local governments and tribes to develop local solutions and share information.
- WSDOT makes information on WSDOT herbicide use, including need and risk, available for the public on-line through the agency's Gray Notebook of accountability measures.

There are currently six counties in Western Washington that maintain their road systems without the use of herbicides. WSDOT developed a Comparison of Roadside Maintenance Practices—Impacts of Herbicide Use on Cost and Results. The findings show that to preserve the same level of service WSDOT maintenance currently delivers, without the use of herbicides, the overall cost of roadside vegetation management would be close to double. WSDOT found that most of the cost increase from herbicide elimination comes from maintenance at the road shoulder. In most cases, WSDOT keeps this area vegetation free; however, in the six counties that do not use herbicides, grass is allowed to grow up to the edge of pavement. Further research will be conducted in the coming years for road shoulder maintenance in areas throughout the state.

Mn/DOT Position Statement on the Use of Herbicides

Mn/DOT Position Statement on the Use of Herbicides states the agency's commitment to

> using the least toxic, efficacious pesticides available for controlling identified pest species. Herbicide selection and use should be based upon scientific information, including but not limited to, efficacy on targets to be controlled, environmental fate, and toxicity. Selection and use of herbicides is further governed by state and federal laws and regulations. Herbicides selected and used are to be applied by licensed applicators except as allowed in the herbicide policy guidelines adopted here under. All applications should be in accordance with applicable laws, regulations, and label instructions.

On-Line Sources of Information

The following is a guide to the use of various herbicides for the management of noxious and nuisance plant species.

- Overview and Using the Corps' Plant/Herbicide Identification System. Herbicides by Plant. Plant lists are organized by habitat type as well as the list of all plants contained in the system. A related herbicide list is included as well.
- Safe Herbicide Handling in Natural Areas: A Guide for Land Stewards and Volunteer Stewards, Upkeep and Maintenance of Herbicide Equipment: A Guide for Natural Area Stewards, and an example of Standard Operating Procedures for Herbicide Use, including a contingency plan in case of spills as well as a

generalized check sheet. All by The Nature Conservancy staff.
- Crop Data Management Systems MSDS Sheets—The Crop Data Management Systems website provides Material Safety Data Sheets (MSDS) for fertilizer and pesticide products of North American manufacturers.
- Herbicide Recommendations: Rangeland Rights-of-Way—Easy-to-use table describing how and when to treat specific weeds with herbicides [Yellowstone County (Montana) Weed Department].
- Development of Weed Resistance as Affected by How Frequently a Herbicide Is Applied—Fact sheet explaining a strategy for decreasing selection pressure by herbicides on weed communities (Western Society of Weed Science).
- Herbicide Resistant Weeds—The development of herbicide resistant weeds is described along with strategies to prevent development (University of Nebraska–Lincoln).

CULTURAL CONTROLS

Cultural control methods introduce and manage desirable plants and covers to control invasive species and other undesirable plants. Many native plants are poor competitors in their early stages of growth; however, once established, they can crowd out most other plants with minimum management. Prevention measures may also be considered cultural controls, and are covered in detail in chapter three. Nine DOTs (23% of respondents) mentioned that they are using cultural control methods; however, the percentage may be considered higher when altered DOT processes and procedures are considered.

Cultural controls include land management practices that inhibit weed growth and prevent conditions that lead to weed establishment. For instance, planting and maintenance activities can be modified to reduce weed infestations. Attention to suitable seedbed preparation and proper fertilization can help prevent colonization by weeds. Planting in narrow rows reduces bare ground and increases the shaded area between rows, further decreasing potential weed habitat.

Many agencies are using native grasses to control invasive species, because their dense, deep root systems inhibit weed growth. Both Minnesota and Iowa DOTs have found success in controlling invasive species and Canada thistle, in particular in Minnesota, using native grass stands (*72*).

Department of Transportation Use of and Research on Prevention Practices and Native Revegetation

Review and Pretreatment of Construction and Materials Sites

Preconstruction planning and treatment to reduce infestations of invasives is on the upswing. Nine DOTs (23% of respondents) reported that all construction sites are reviewed for invasive species before opening. WYDOT is among five that are working at pretreating construction zones before soil disturbance.

WYDOT is attempting to develop a more aggressive pit assessment and treatment program with local Weed and Pest districts. These sources have been identified as having the greatest potential for spreading invasives. At NDOT, a staff biologist surveys material source sites for invasives. When invasives are found, a management plan is developed in cooperation with the local BLM weed coordinator or botanist. Environmental Services is developing standard noxious weed control BMP specifications for weed management on material and project sites. Eight other DOTs (23% of respondents) also ensure that dirt and gravel sources are evaluated. In addition:

- More than one-third of DOTs (17) specify weed-free mulches on all projects. Inert mulch products such as straw or wood fiber are used in sensitive areas by 11 DOTs (28% of respondents).
- Twenty-one state DOTs (53% of respondents) specify on project plans and bid contracts that seed and sod sources must be free of invasive species and/or weeds.

Possible solutions to the problem of weeds that are introduced by animal feed or mulches contaminated with weed seed are discussed in "Certified Weed Free Forage: An Emerging Program for Western States" (*100*).

Protection of Native Populations

Intact communities of native species both suppress invasives and shelter rare species. Thirty-eight percent of responding DOTs (15 states) are now screening for the presence of rare plant communities in the work zone or ROW. In 13 states, areas in need of special management are identified by resource agencies or the state NHP. NCDOT, like many others, works cooperatively with their state Department of Environment and Natural Resources, in-house botanists, and others to identify and protect state and federally endangered plant and animal species found on its ROWs. ODOT has labeled special management areas that indicate the types and timing of maintenance techniques that are to be done. Because WisDOT hires county highway departments to perform highway maintenance, the agency has let several contracts to manage and restore high-quality remnant plant communities discovered on the ROWs. Management plans are often developed to inventory and ensure appropriate management of special areas. Ten DOTs (25% of respondents) have mapped and tracked protected communities on the statewide DOT ROW.

Staff at 14 DOTs (35% of respondents) identified special management areas, which are managed accordingly by

maintenance employees. As Illinois DOT noted, commitments are added to plans and DOT staff are trained on how to maintain these areas through mowing, herbicide applications, and burning. Protected species are identified and restricted maintenance practices are incorporated to protect the endangered species; construction practices are also altered to minimize disturbances of native plant communities whenever possible. In several states, special vegetation management programs have been developed to protect Karner Blue Butterfly habitat, including mowing date restrictions and native blue lupine and butterfly weed restoration planting and seeding. LADOTD has taken high-value remnant strips in several districts and moved them just beyond the ROW, with the consent of the owners of that property and following discussions regarding proper management. If moving them is determined not to be an option, LADOTD marks the site to prevent herbicide applications or mowing at the wrong time of the year.

In most cases, DOTs are undertaking these conservation measures without knowing the total acreage of high-quality forest, wetland, or native grassland remnants they have or are protecting in the ROW. Just 15% of those responding (6 states) could provide such an estimate if asked. More than one-third of DOTs (43% of respondents, 17 states) identify native and rare plant communities in EAs and EISs. In particular, Hawaii DOT indicated that most of their protected areas have been identified as a result of EAs, EISs, and special management areas.

Vehicle Cleaning Practices

Vehicle and equipment cleaning procedures and practices are typically used to minimize or eliminate the discharge of pollutants from vehicle and equipment cleaning operations into storm drain systems or watercourses, and to minimize transport of invasive species. Twenty-three percent of responding DOTs (9) reported that they ensure vehicles are washed before and after use to control the spread of invasive species. Caltrans is among the DOTs that have developed an extensive set of construction vehicle cleaning environmental stewardship practices (*101*).

Revegetation

Some DOTs are undertaking research to identify what vegetation establishment methods work best in their states and ecoregions. Studies on compost usage have been undertaken in the West and Midwest, from Texas in the south to Idaho in the north. The Nebraska Department of Roads research results will be used to develop technical guidelines for vegetation establishment on roadway shoulders. The project is examining the interaction effects of seed priming, type of mulch, and level of irrigation on soil movement and establishment of the short grass mixture on the foreslope of roadway shoulders; the interaction effects of composted manure applications and a 6- to 12-in. compacted buffer strip between the paved shoulder and the seedbed on soil movement; and establishment of the short grass mixture on the foreslope of the roadway. Delaware DOT is also publishing a vegetation management manual, in conjunction with the agency's tree preservation policy for a Livable Delaware (*102*).

Soil Management on Construction Sites

Soils management on construction sites is an important factor in invasive species control. Just 12 state DOTs (30%) reported that they stockpile desirable and uncontaminated topsoil to facilitate revegetation. Topsoil has become a commodity that contractors often strip and sell. In addition to removing native cover that may effectively compete with invasive species and opening new pathways for infestation, the change in soil characteristics that may occur with loss of topsoil can also bolster invasives. One Florida study on roadside soils and invasive species suggested that disturbance alone may not increase the presence of invasive species, but that a change in soil characteristics through the addition of clay and limerock from road construction may enhance invasion (*103*).

Claassen et al. (*104*) have performed a number of studies on topsoil usage and compost, with funding from FHWA and Caltrans. Their work and recommendations augment that of DOT handbooks, and are summarized in AASHTO's *Environmental Stewardship Practices, Procedures, and Policies for Highway Construction Maintenance*. Among its many helpful recommendations are for DOTs to test nitrogen content in soils and ensure slow-release of amendments over 3 years, use compost instead of commercial fertilizer, and ensure that compost amendments have adequately decomposed. Where topsoil is not available other amendments can be used; the quantity and quality of the nitrogen materials applied is critical. The nitrogen release should be slow enough to keep plant-available nitrogen at modest levels; however, the total amount of nitrogen amended should be high enough so that the site does not run out before the plant community is well established. For example, the nitrogen amendment should be able to support 3 to 5 years of plant growth. Controlled release of nitrogen is important because excessive nitrogen availability promotes weedy annual grass growth, drying out the site and crowding slow growing perennials. Although the maintenance of moderate, sustained nitrogen levels may be achieved from commercial, slow-release fertilizer sources, the inclusion of organic matter in the amendment is also important to improve the hard setting and poor water holding capacity of low organic content materials. Biomass associated with compost has been more effective than nitrogen amendments that were evenly distributed throughout the profile (0–30 cm) or applied deeply within the profile (20–30 cm) (*105*). Studies of plant communities established on "problem soils" amended with commercial fertilizers have shown vigorous initial growth; however, that vegetative cover often becomes sparse or nonexistent within several years

(*106*). In addition to transportation-related studies, those of fertilized mine reclamation spoil observed that revegetated areas tended to be highly productive for 2 to 5 years, followed by a sharp decline in plant growth and nutrient availability (*107*). Reapplication of topsoil to subsurface materials enhanced reestablishment of vegetation by increasing nutrient availability, water holding capacity, and microbial activity (*108*). Compost can be used to replace the organic matter and nutrients and can act as a surface mulch to protect against erosion, extreme temperatures, and drought (*109*).

Long-term nitrogen release rates from most yard waste compost materials approached the nitrogen release rates of moderately fertile soils. Composts were shown to be able to regenerate the nitrogen availability characteristics of low-nutrient substrates that have been stripped of topsoil organic matter. Well-cured composts and co-composts (biosolids blends) approached the nitrogen release rates of highly fertile soils. Compost application provides longer nitrogen release duration compared with chemical fertilizer and also provides organic materials for improved infiltration and microbial activity. Potential compost sources and soils at the site should be analyzed before amendment, because compost products and the soils that are to be revegetated vary in fertility and water availability.

Shoulder Grading

DOTs are teaching maintenance staff that shoulder grading is not acceptable as a method of vegetation or invasive species control. Shoulder grading is only promoted as a means of refining lateral support for the road.

Managing the Roadside as an Asset: Value Engineering and Invasive Species Prevention

With the advent of modern herbicides, prevention as a weed management technique has been neglected. WSDOT discovered the following through the agency's value engineering work:

- Some of the biggest problems in relation to roadside vegetation management and invasive species control stem from inadequate consideration of soil conditions, restoration of desirable roadside vegetation, and weed control in design and construction.
- Through the value engineering study, WSDOT identified a series of recommendations that, if implemented, could result in improved weed control and reduced herbicide use over the long term; in effect, reducing the roadside maintenance requirements over the life cycle of the highway.
- Recommendations resulting from this study for improving weed control and reducing long-term vegetation maintenance requirements through design and construction were grouped into four categories.
  - Pavement edge treatment—use of topsoil and low-growing native grass species in place of unvegetated crushed rock along the edge of pavement.
  - Soil amendment—use of compost and mulch as amendments to raw mineral soils on cut and fill slopes.
  - Weed control during construction—ensuring adequate funding, specifications, and inspection provisions to prevent weed transport and establishment during construction.
  - Establishment of desirable low-maintenance vegetation—planting and effective establishment of native shrub and tree community on the back slopes and areas away from the traffic lanes.
- If all these recommendations can be carried out effectively, the only maintenance requirements will be occasional selective removal of weeds and undesirable trees and brush. With proper care for the planted materials over time, maintenance requirements should decrease as the roadsides become more established.

Similar to WSDOT, Caltrans performed a study on how to successfully implement an IVM program in its diverse ROW corridor network. The main goals of the study were to develop better processes for roadside design and consideration of long-term maintenance (life-cycle costs) and develop strategies that satisfy safety, environmental quality, herbicide reduction, cost-effectiveness, and public perception goals. Caltrans decided that process revisions were necessary to Caltrans Design, Project Development Procedures, Construction, and Maintenance manuals. In particular, cross-functional teams of skilled district and/or headquarters staff, such as landscape architects and landscape specialists, were recommended to ensure that life-cycle maintenance and corridor management issues are considered throughout project development. In addition, Caltrans decided that ROW corridor master plans needed to be developed to map out a future vision for ROW corridors in the state, because of the close relationships between vegetation management, stormwater management, scenic resources, environmentally sensitive areas, and many other issues, recognizing the relationships of these issues and determining how they are affected by highway design and management. The master plans characterize each roadway segment, indicating aspects such as invasive species, scenic resources, environmentally sensitive areas, special status species, adjacent land use, projected average daily traffic, and other factors, and prescribe the objectives for the roadway. The master plans are to be coordinated with federal, state, and local jurisdictional agencies to optimize resources and ensure consistency with other developed plans. The ROW corridor master plans enable:

- Designers to consider the predetermined and cultural issues associated with a corridor segment.
- Landscape architects to reference native species and establish overall site-specific objectives for highway plantings.

- Maintenance personnel to be aware of environmentally sensitive areas and prescribe best management practices.
- Systematic upgrades and retrofits of facilities as new designs become available.
- Cooperative management efforts with local public works agencies.

In their alternatives analysis of different vegetation management methods, Caltrans found that one of their top-ranking alternatives was the use of preferred vegetation species, because roadside environments often favor invasives and are not supportive of native species. Caltrans identified the planting of species that do not require ongoing maintenance and do not threaten adjacent resources or safety as one of the best strategies for minimizing vegetation control problems.

Revegetation Through Restoration of Native Species

Most weeds are opportunistic and become established following a disturbance or opening in the canopy. Therefore, it is very important to cover the soil with dense, vigorous vegetation to prevent the establishment of invasive species. Because weed treatments often disturb the soil, open the canopy, or leave bare soil, revegetation after treatments is crucial in suppressing weed seedlings and preventing weed infestations from reoccurring. Although restoration efforts have certain elements in common, each invasion and area is unique. Revegetation and restoration projects need to be based both on general principles and site-specific considerations and analysis. Monitoring programs are necessary to track the success of control and restoration efforts and to ensure that the area is not reinvaded.

Executive Order Mandates Regarding Native Species Restoration

E.O. 13112 requires federal agencies to "provide for restoration of native species and habitat conditions in ecosystems that have been invaded." In the long run, such restoration areas should require little to no maintenance. According to *NCHRP Synthesis of Highway Practice 341* (*67*), on average, 58% of DOTs' newly planted acreage requires no significant maintenance work on a perpetual basis; 23% indicated that less than 20% of the newly planted acreage requires significant maintenance work on a perpetual basis. Approximately one-quarter of responding state DOTs were aiming for 90% to 100% of planted acreage requiring no significant maintenance work on a perpetual basis.

Restoration is an integral component of comprehensive prevention and control programs for invasive species that may keep invasive species from causing greater environmental disturbances. Revegetation with native species provides better adaptation to the site and a more natural appearance than introduced species, which would have the potential to escape into the natural environment. An earlier Federal Executive Memorandum on beneficial landscaping became effective in April 1994, encouraging the use of native plants as much as practicable on all federal lands and in all federally funded projects. In 2000, this Executive Memorandum was incorporated into Executive Order 13148 on the Greening of Government. Executive Order 13148 also required agencies to purchase "environmentally preferable and recycled content products, including compost and mulch that contribute to environmentally and economically beneficial practices" (*110*).

FHWA Recommendations for Designing with Native Vegetation

FHWA recommends the following considerations and specifications in designing with native vegetation (*9*):

- Use natural region maps commonly available from the state's NHP instead of cold hardiness zones when designing with native plants. Visit native plant preserves that can serve as references for plantings. The NHP can recommend sites.
- Use seed mixes specific to the different conditions on the site. Dry conditions may be present on sandy slopes or forest edges and wet conditions in ditches, requiring different or adjusted mixes in these areas.
- Eradicate invasives from the site before planting.
- Consider a line item for the contractor to control invasives and clean equipment.
- Plant as much diversity as possible, unless an adjacent native seed source exists.
- Match site microclimates with distinct seed mixes as much as practical.
- Specify a locally grown or collected source if possible. Most native species will establish more easily if locally grown or collected.
- Order native seed when the contract is let to prevent unwanted substitutions.
- Limit bids to experienced contractors and approved vendors for these projects.
- Separate the planting contract from the general contract for best timing.
- Extend the establishment period to 3 years.
- Learn appropriate seed test criteria and seeding rates to avoid waste.
- Plan for seed collection and plant salvage if native remnants will be disturbed by the project.

Department of Transportation Revegetation Practices—Survey Results

As part of their commitments to reduce invasive species and to develop attractive and sustainable roadside environments that are better for native species and agency budgets, many DOTs are turning to native revegetation projects and plans.

The survey for this project found that 44% of DOTs reported that they rely on native grasses and forbs.

Primary actions DOTs have taken to implement the use of native grasses and forbs in erosion control, landscaping, and revegetation include those shown in Figure 5. The percentage DOTs that indicated use of this action is included.

- Required seed mixes have been designed for a variety of ecoregions and slope aspects—43% of respondents (17 states).
- Special provisions are included in contracts for particular projects—45% of respondents (18 states).
- DOT policies or agency-wide design specifications require the use of native species—38% of respondents (15 states).
- Landscape architect comments on landscape plans during reviews—33% of respondents (13 states).
- Vegetation and revegetation is performed according to a statewide or regional vegetation plan—18% of respondents (7 states).

Policies or Plans Specifying Native Revegetation

Policies or plans specifying native revegetation are already in place in 17 states (43% of responding DOTs). Another 10 states (25% of respondents) have plans specifying native revegetation on some projects or corridors. A statewide plan for native revegetation is in the process of being developed at five state DOTs (13% of respondents), Hawaii, Minnesota, Montana, New Hampshire, and New York State. States indicated that they believed their plans were generating results.

Increasingly, plans are being developed in coordination with other agencies. For example, Connecticut DOT has coordinated with the state's Department of Environmental Protection and the National Resource Conservation Service to ensure that the DOT's revegetation policies and agency-wide design specifications are in agreement with those of the resource agency. In a few other cases, state DNRs or agriculture departments are developing plans in conjunction with DOTs or on which DOT plans will be based.

Some state DOTs have been pursuing native revegetation or relying on native species in their seed mixes for 20 years or more (WYDOT and Nebraska Department of Roads). WisDOT used the 1987 Surface Transportation and Uniform Relocation Assistance Act (STURAA) to fund the ongoing use and preservation of native plants. STURAA contains a mandatory requirement that native wildflower seeds or seedlings or both be planted as part of landscaping projects undertaken on the federal-aid highway system. At least one-quarter of one percent of the funds expended for a landscaping project must be used for native wildflowers. WisDOT established a waiver that allows the agency to avoid planting native wildflowers where doing so would be inappropriate, and save the unused funds for larger projects in the future. WisDOT also creates or preserves native plant conservation sites where possible to serve as conservation banks for unavoidable impacts.

Caltrans manages and is adding to 20 Botanical Management Areas (BMAs) throughout the state, which harbor "significant native vegetation remnants that are self-sustaining, botanically diverse, and provide aesthetic enhancements to the roadside environment." The areas help the agency satisfy STURAA requirements. Since 2003, Caltrans districts have been asked to "identify and program native landscape restoration projects with a goal to develop sustainable rural landscapes" programs as "highway planting restoration" in the state operations budget (*111*).

An ecologically based program of roadside vegetation design and management seeks to produce low-maintenance, self-sustaining plant communities. WSDOT defines sustainable roadsides as those roadsides that are designed and maintained with the intent of integrating successful operational, environmental, and visual functions with low life-cycle costs (*112*). The use of native plants planted in the right location is integral to achieving such a sustainable system. This requires good stewardship practice in design.

- Include a landscape architect in the design development process to improve the design, environmental, and visual quality of the roadsides, and chances of planting success.
- Consider construction requirements such as site accessibility and constraints such as contract timing in design documents.
- Ensure that invasive species are addressed and not incorporated in plantings. Check with the state's noxious weed control board for a list of invasive species in the state, if not available through the DOT.
- Review and comment on plans during development of specifications and engineering. Maintenance review (such as by the maintenance supervisor in charge of the contract area) is essential, because DOT maintenance crews often maintain landscape projects after installation.
- Have project partners review design documents and plant material selection before installation. Some projects have special partnership arrangements; for example, the DOT might require the project sponsor or partner to maintain plant communities. Project sponsors have included cities, counties, tribes, transit agencies, and other agencies, that can often contribute labor, funding, and materials.

Seed Mixes Are Designed for Native Restoration

More than one-third of state DOTs have seed mixes designed for all or most projects; 8 states (20%) design seed mixes for every project, and another 10 (25% of respondents) do so for most. Thirty-eight percent of responding DOTs have developed

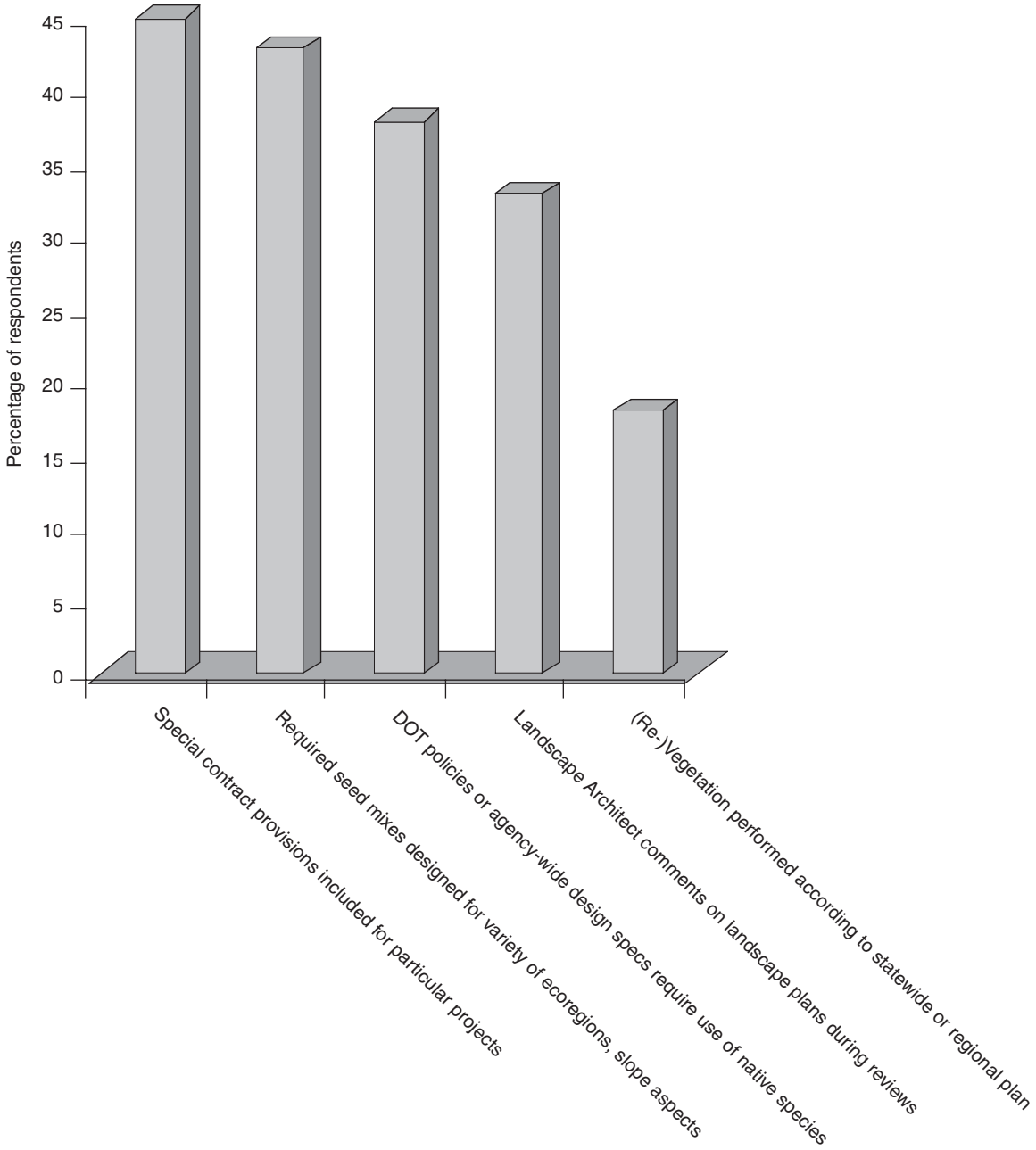

FIGURE 5 Survey results of DOT revegetation practices.

seed mixes for each ecoregion. Thirty percent of respondents modify seed mixes for project microclimates.

It is more common for custom mixes to be developed on capital projects; maintenance forces more often draw on standard seed mixes. Mn/DOT, PennDOT, and other DOTs have designed and specified special seed mixes for areas outside of the standard highway construction slopes, including wetlands, wildlife habitat, and streambank mitigation.

- Design for project sites, ecoregions, and distance from roadway—Thirty-three percent of responding DOTs reported that seed mixes are not designed for each project. Another 5% noted that they do not yet have such mixes, but are developing them. Missouri uses three main seed mixes statewide, not divided by ecoregion but by distance from the road; one mix for the first 30 ft, another mix for the next 30 ft in urban settings, and another for beyond 30 ft in rural settings.
- Variable amounts of native grass and forbs per mix—The amount of native grass and forb species per mix varies in some cases by state and landscape architect. Native seed portion of the mix ranges from 60% in Maryland to up to 100% in Rhode Island and Wisconsin. Of the states responding to this question, most were in the 85% to 90% range. For Caltrans, the proportion depends on the landscape architect designing the mix.

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- Available expertise—Seed mix customization requires a certain amount of ecological or botanical expertise. Forty-three percent of responding DOTs believe that they have adequate expertise available in their agency to cover the demand. Forty percent of responding DOTs indicated they could use more help in this area. Some DOTs said they had available expertise on staff, but that staff needed more time.

Availability of Native Seed Sources

Native seed sources are available in most states, although only 33% of responding DOTs stated that they have several sources available and an adequate supply. In five states, no native seed sources are available locally. Sources are insufficient to meet demand in 13 other states (33% of respondents) (see Figure 6).

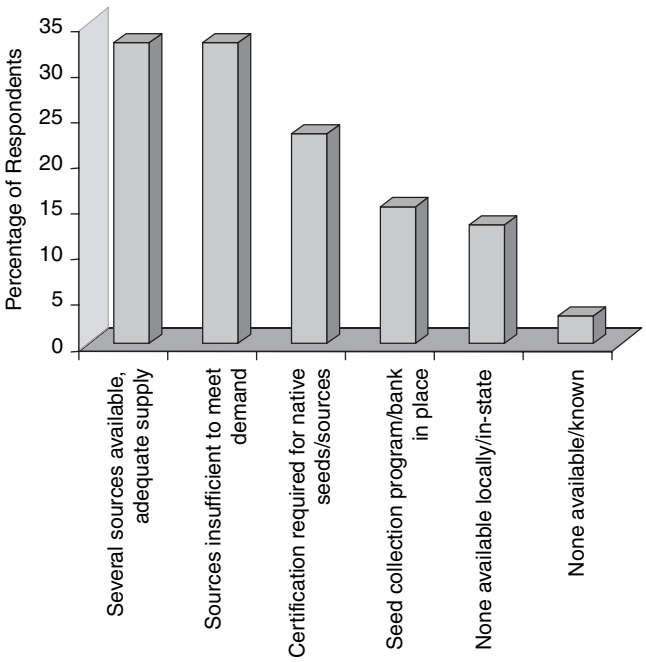

FIGURE 6 Native seed source availability.

Just over one-third of state DOTs are facing supply problems in acquiring native seed. To address such needs, LADOTD developed a federal-aid project ($1.7 million over 5 years) to develop a wildflower seed bank pilot program using native species grown in state. LADOTD is also working with three universities across the state to ensure that native species are developed for use on ROWs.

Seed collection programs or seed banks are in place in six states (15% of respondents). Nine states (23% of those responding) require certification for native seed sources. Four states specify certified native seed sources only (Arizona, Nebraska, New Mexico, and Texas). The Arizona DOT requires seed tests as well. Other DOTs, such as Iowa, give weighted preference to certified or source-identified seed or are just beginning to track where seed comes from. Virginia DOT indicated an interest in increased focus on germination rates for native seeds and/or ensuring noncontamination with invasive species, because germination rates for native species have presented a problem. Some DOTs are interested in harvesting more seed from native species on the ROW; however, at least one DOT indicated an interest in not being mandated to use wild-harvested seed because it could hamper revegetation efforts.

Primary Obstacles in Greater Use of Native Species

Primary obstacles indicated by DOTs in employing greater use of native species are length of time to establish and cost of desired materials and/or available agency funding. In each case, 17 states (43% of respondents) cited these as key obstacles. In addition to cost and establishment, multiple states found the following to be primary obstacles (see also Figure 7):

- Availability of plant material or desired seed mixes—16 states (40% of respondents).
- Limited research regarding what works—15 states (38% of respondents).
- Public's desire for ornamentals or other non-natives considered more aesthetically pleasing—15 states (38% of respondents).
- Acceptance/education internally or among contractors—12 states (30% of respondents).
- Contracting process and lack of control over contractors' schedules—8 states (20% of respondents).
- Other agency requirements—15% of respondents. For example, WYDOT believed that federal resource agencies have recently held back native revegetation efforts in some areas by requiring untested, wild harvested plant materials to be used on federal lands.
- No answer—15% of respondents.

DOT vegetation management personnel also identified the following as problematic:

- Intense invasive seedbanks in some cases adjacent to the ROW.
- Contract language for establishment of native grass within contract because the work required is dynamic and changing with the seasons; that is, "adaptive management."
- Weed control during establishment period requires a greater investment than field maintenance resources can provide.
- Adjacent land owners mow, hay, and spray plantings.
- Outdated temporary seed mixes.
- Commitment from the department.
- Roadside turf mixes generally end up looking the same after years because it is difficult to maintain a prairie strip without prescribed burns.

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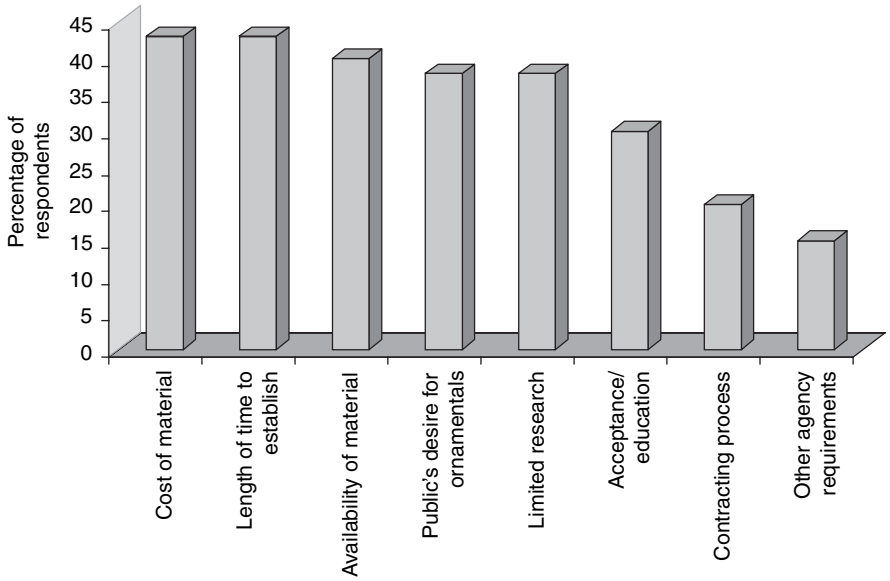

FIGURE 7 Obstacles to native seed use.

- Availability is sometimes controlled by contractors and vendors who bring in seed from too far away.
- Resource agency requirements in some cases for very localized seed collection.
- Confidence in ability to successfully establish erosion-resistant stands of native (warm season) grasses.
- Limited research for our climate and applications, seed availability, short planting seasons, and the plants' perennial nature (two seasons to establish).

As indicated by Caltrans, non-native ornamentals continue to be used in many landscaping projects, although native species increasingly dominate in nonlandscaped or rural revegetation projects. Thirty-eight percent of responding DOTs reported that they do not rely on native grasses and forbs in erosion control, landscaping, and revegetation. For example, PennDOT noted that "native plants are not always the best plant for the roadside environment." However, many of those DOTs that do not necessarily rely on the use of native species report that their use is increasing, new internal resources are being developed, and native seed sources are being located.

Several states indicated that Clean Water Act Nonpoint Discharge Elimination System requirements and the need to achieve prompt ground cover and stabilization after construction worked against the use of native species. However, a number of those states are using mixtures of quick germinating species to avoid erosion and native species for longer-term revegetation. Missouri and Kansas DOTs described the use of seed mixes, including warm and cool season grasses, outside of the clear zone in rural areas of the state. All of the warm season grasses are native species. Mn/DOT reported that "although the pendulum shifted to nearly all natives in seed mixes during the late 90s, we have shifted to mixes that provide quick and reasonably sustainable cover; with the development of compatible and economical mixes of native cool season with warm-season grasses our goal is to increase our use of natives."

Communication difficulties emerge from time to time as well, especially in the absence of systems to prevent mishaps. Several DOTs mentioned areas revegetated in native grasses or wildflowers being inadvertently mowed.

Resources to Assist Designers

The following resources may assist designers.

- The Natural Areas Association, an international nonprofit organization with a mission to preserve natural diversity, provides information on appropriate management of natural areas.
- Nature Serve Explorer is an online encyclopedia for 50,000 plants and ecological communities in the United States and Canada. With the common or scientific name of a plant, it is easy to locate the life history, distribution map, and more.
- Center for Plant Conservation website offers a state-by-state directory of conservation contacts.
- Northern American Plant Society provides an easy way to contact state and provincial native plants plant societies.
- The Native Plant Initiative, an interagency coalition, has worked to share information and resources to improve public awareness, educate their own forces, increase planting success, and more. Their Plant Conservation Alliance can be found online.

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- USDA Natural Resources Conservation Service provides a national plants database.
- FWS provides a national list of plant species that occur in wetlands.

DOTs have developed a variety of formal and informal resources and tools to assist designers as well. For example, Caltrans recognized that the successful establishment of beneficial and native species is dependent on a process of detailed site evaluation, selection of appropriate species, adequate site preparation, and choosing the proper planting technique. To support the successful establishment of beneficial species, Caltrans developed a matrix that identifies and categorizes more than 20 botanical, horticultural, and environmental factors that should be considered for determining the appropriateness and suitability of a given species for a specific ROW segment.

Research Needed Regarding "What Works"

A number of DOTs requested more information on successful practices. DOTs noted the following needs:

- Warm season grasses that will quickly establish and provide a sufficient ground cover.
- Treatment of topsoil.
- For native seeding areas where burning is not feasible.
- Seed mix design with nonburn-dependent species.
- Best practices for timing and frequency of mowing and haying of traditional native mixes.
- Seed establishment of Cyperaceae species.
- Native seeding in sites with low precipitation, heavy infestation by non-natives, or steep slopes.
- Specific research for climate and applications, such as the northeastern United States or eastern Washington State.
- Guidance on controlling less desirable vegetation in areas earmarked for native grasses.
- Complete survey of what native grasses exist within the state and where they occur.
- List of species that survive in high salt and pollution areas.
- Information on the establishment, performance, and maintenance characteristics of native vs. non-native grass seed mixes.

Iowa Department of Transportation Revegetation Program Controls Invasive Species

Although many state DOTs have begun to mandate the use of native species when revegetating construction sites, Iowa DOT has extended their landmark IRVM program to annually revegetate approximately 2,200 acres of targeted roadside areas not connected to any construction projects. Another 3,200 acres of roadside on construction sites are seeded annually with native grasses and forbs.

Iowa DOT and many Iowa counties have shifted from traditional roadside maintenance of a monoculture of exotic grass in favor of management regimes that restore native vegetation and reduce the use of herbicides and mowing. Iowa DOT has identified maintaining a healthy stand of native grasses as the best way to control invasives. These grasses have extensive roots that offer the toughest competition to Canada thistle. In addition, plant diversity along the roadsides creates a strong plant community. Prairie plants can adapt to a wide range of soil types, moisture levels, and climactic conditions. Most prairie grasses and wildflowers grow best during hot, dry summer months, providing excellent erosion control during the fall and spring.

Iowa DOT recently extended their landmark IRVM program to revegetate approximately 5,200 acres of roadside annually with native grasses and forbs. Forty percent of that acreage is restoration unrelated to construction (*113*). The program is documenting species diversity and wildlife benefits as well. Twelve roadside areas were surveyed for abundance and species richness of disturbance-tolerant and habitat-sensitive butterflies and compared with nearby roadside dominated by primarily non-native legumes and/or grasses. Species richness of habitat-sensitive butterflies showed a two-fold increase on restored roadsides compared with grassy and weedy roadsides. Abundance increased five-fold for native grass and forb habitat over non-native. Tracking studies found that butterflies were less likely to exit the restored roadsides, indicating that mortality rates may be lower and offering preliminary evidence that roadsides have the potential to be used as corridors (*114*).

SUMMARY OF DEPARTMENT OF TRANSPORTATION SURVEY RESULTS—POPULAR AND INNOVATIVE CONTROL STRATEGIES

The survey conducted for this synthesis heard from 40 state DOTs. Results are summarized here.

- Weed-free mulches are specified on all projects (17 DOTs, 43%)—CA, CO, IA, KS, MA, MN, MS, MT, NV, NH, NC, OR, RI, UT, VT, VA, WA.
- Specifications are in place on project plans and bid contracts that seed and sod sources must be free of invasives and weeds (21 DOTs, 53%)—AK, CA, CO, CT, IL, MA, MN, MT, NV, NH, NC, OH, OR, PA, RI, SD, UT, VT, VA, WA, WI.
- Inert mulch products such as straw or wood fiber are used in sensitive areas (11 DOTs, 28%)—CA, MA, MN, NV, NH, NC, NY, OR, RI, VA, WA.

- Desirable and uncontaminated topsoil is stockpiled to facilitate revegetation (12 DOTs, 30%)—CA, MA, MN, MT, NV, NH, NC, OR, RI, VT, VA, WA.
- All disturbed areas are restored through application of grass seed and mulch within 2 weeks of disturbance (14 DOTs, 35%)—CT, IL, IA, MA, MN, MT, NH, NC, NY, OR, RI, VT, VA, WI.
- Biological controls (e.g., insects) are used (13 DOTs, 33%)—CA, MA, MN, MT, NH, NC, NY, OR, RI, UT, VT, WA, WI.
- Mowing is timed to control invasive species; that is, before seed maturity (12 DOTs, 30%)—IL, MA, MN, MT, NC, NY, OH, OR, PA, RI, WA, WY.
- All construction sites are reviewed (9 DOTs, 23%)—CA, CT, NV, NH, NC, RI, UT, VA WY.
- Handpicking of invasive species is employed in some areas (10 DOTs, 25%)—AK, CA, CT, FL, IA, MN, NV, NY, UT, WA.
- Mowing occurs in an order to minimize seed transfer (10 DOTs, 25%)—CT, IL, IA, MN, MS, NH, NC, NY, OH, RI.
- Native seed mixes use native grass and forb species (9 DOTs, 23%)—CA, KS, MA, MN, NH, OR, RI, UT, WI.
- Cultural control methods used (9 DOTs, 23%)—CA, IL, IA, MN, NH, NY, OR, WA, WI.
- Dirt and gravel sources are evaluated (9 DOTs, 23%)—MT, NV, NH, NC, NY, OR, RI, VA, WY.
- Vehicles are washed before and after use (9 DOTs, 23%)—CO, IL, KS, MT, NV, NY, NC, OR, UT.
- Native seed sources are specified and only regional ecotypes are used (7 DOTs, 18%)—CA, KS, NV, NH, OR, RI, WI.
- All ROWs are reviewed and treated annually for invasives (6 DOTs, 15%)—MT, NC, SD, VA, WA, WY.
- Contract grown native plants have been used when economically justified (7 DOTs, 18%)—CA, MN, MT, NC, NY, RI, UT.
- Policies are in place and enforced to minimize disturbed and opened areas; that is, construction phasing (7 DOTs, 18%)—CA, IA, NH, NC, NY, RI, UT.
- Restoration (7 DOTs, 18%)—CA, IA, MN, NH, NY, OR, WA.
- Badly infested material is excavated and buried (6 DOTs, 15%)—CT, MA, MS, NH, NY, UT.
- Construction sites are pretreated before disturbance (6 DOTs, 15%)—IL, MN, NY, OR, UT, WA.
- For all projects and activities, consider impacts for priority invasive plant and animal species (6 DOTs, 15%)—IL, NV, NH, NC, NY, OR.
- Controlled burning (4 DOTs, 10%)—CA, IL, MN, WA.
- Contractors are prequalified based on experience and quality of work (2 DOTs, 5%)—NH, NC.
- Grazing (1 DOT, 3%)—CA.
- Roadway shoulders are treated before scraping (1 DOT, 3%)—NV.

DOTs also noted innovative models of methods, equipment, and bids they were using for specific species and more generally.

- A combination of prescribed fire and chemical control has proven most effective for camelthorn (*Alhagi maurorum*), and also for starthistle species (Arizona).
- Spray fescue in the fall with two additional applications in the spring before planting native species (Indiana).
- Beetles for biocontrol on graveyard spurge (*Euphorbia cyparissias*) shows this nontoxic strategy to be effective (Minnesota).
- Stem injection for multiple species of knotweeds (Washington State). NYSDOT also noted syringe injection of herbicides for invasive species control.

More general recommendations, observations, and resources recommended by the state DOTs included:

- Use of a Brown Brush monitor (Minnesota and Washington State).
- Soil resource evaluation research—a final report to be posted on the Caltrans Landscape Architecture home page (California).
- Basal application crews included in the herbicide spray contracts (Pennsylvania).
- Using Thinvert spray carrier in place of water to increase the acres treated by a single tank (Pennsylvania).
- All 325 herbicide trucks are built in-house and much of the smaller specialized equipment is also built in-house on an as-needed basis (Texas).
- Properly timed use of slow release liquid fertilizer (Washington State).
- LADOTD has found that over-application of soil sterilants to eliminate problem species has opened up areas for other weeds to establish themselves, creating unattractive areas that require reseeding as soon as possible to help minimize treatment spots.
- WisDOT has been letting prairie remnant contracts using specifications in the manner typical of normal highway construction projects, and has found that a more flexible system would be more desirable. WisDOT is exploring the use of a Request for Proposal process that would describe expected outcomes and let the bidder describe how to accomplish them.

When asked if their invasive species control strategies were limited by authority and/or funding, 10 DOTs (25% of respondents) said they were *not* limited by a lack of authority. Seventeen DOTs (43% of respondents) said that they *were* limited by a lack of authority. A larger number of DOTs believed that their invasive species control strategies were hampered by inadequate funding. Only three DOTs indicated they did not feel that way (8% of respondents).

DEPARTMENT OF TRANSPORTATION ON-LINE ROADSIDE MAINTENANCE GUIDANCE, MANUALS, AND PROCEDURES

State DOTs have created the following guidance, procedures, tools, and manuals that may be used by other DOTs:

- Caltrans guidance for E.O. 13112.
- Caltrans Roadside Management Toolbox and Information on development of the Roadside Toolbox of specifications, tools, and guidance.
- Caltrans Highway Planting and Irrigation.
- Caltrans *Maintenance Manual*; Caltrans *Highway Design Manual;* and Caltrans *Stormwater Quality Handbook, Project Planning, and Design Guide*.
- FDOT Procedure #850-000-015-f, Roadway and Roadside Maintenance.
- Iowa DOT roadside management guide containing collections of plant profiles, characteristics, requirements, and how these species are used in roadside management.
- Mn/DOT seeding manual.
- Mn/DOT herbicide policy and the attached partial list of pests and possible control measures along with precautions.
- *Minnesota Best Practices Handbook on Roadside Vegetation.*
- Mn/DOT Integrated Roadside Vegetation Management.
- MDT Statewide Integrated Weed Management Plan, 2003–2008.
- Nebraska Department of Roads Mowing Guidelines.
- Nebraska Department of Roads *Roadside Chemical Usage Guidelines*.
- *NYSDOT Environmental Procedures Manual,* Chapter 4.8, Invasive Species, 9/10/04.
- NCDOT Vegetation Management Maintenance Program.
- Oregon 2005 Noxious Weed Policy and Classification System.
- PennDOT *Design Manual 2*, Section 8.1 Planting Design.
- Pennsylvania Code Chapter 110: Noxious Weed Control Law.
- WSDOT Roadside Classification Plan.
- WSDOT *State Roadside Manual*.
- Washington State IVM for Roadsides.
- WisDOT Best Practices for Control of Certain Invasive Plant Species.
- WYDOT Policy and Procedure Directive for Noxious Weeds and Construction Projects, P&PDIR98-02.
- Wyoming Weed Management Plan.

CHAPTER FIVE

STAFFING, TRAINING, AND PARTNERSHIPS FOR INVASIVE SPECIES CONTROL

Increasingly, DOTs are hiring a central staff person to coordinate invasive species control efforts among functional areas within the agency and to coordinate contracting and partnerships with others.

CENTRAL INTEGRATED ROADSIDE VEGETATION MANAGEMENT STAFF

Seventy-three percent of responding DOTs have central staff for their IRVM programs (29 states). Several states listed this as their most effective action in controlling invasive species. MDT noted that "hiring an individual to be the focal point for noxious weeds has enabled the DOT to focus on management techniques, cost-effectiveness, and inventory." Iowa DOT reported that, although this program has been discontinued in most of the state, designating selected field personnel responsible for vegetation management and providing them with training, networking opportunities, and dedicated equipment was the most successful thing the agency has done for noxious weed control to date. In 13 states, roadside managers in each district manage planning for and awareness of invasives.

OTHER STAFFING PLANS FOR ADDRESSING INVASIVES

Half of state DOTs indicated that they have no particular staffing plans for addressing invasive species concerns. The 11 states (28% of total responding) that did indicate plans to address staffing needs varied widely in approach.

- All work is performed by state employees (Alabama and Texas). Pennsylvania uses existing roadside vegetation management personnel to control invasive species; however, 90% of the vegetation spray applications are done by contractors. For tree removal, 80% is done by contractors and 20% by department employees, with 70% of the mowing done by contractors and 30% by PennDOT. Arkansas Highways is among those that contract out some mowing to private contractors.
- In Arizona, some work is handled by the DOT; counties, tribes, other state and federal agencies, and volunteer groups, such as various WMAs take the lead in other areas. Cities and counties handle much of their own invasive species control in Nebraska, New York, and Texas.
- At FDOT, districts and maintenance yards decide whether to use state employees or contract out.
- At Mn/DOT, districts determine staffing and material needs based on weed surveys and sampling.
- Hawaii, Nevada, and Wyoming DOTs collaborate with the state DOAs and Invasive Species Councils to handle high-risk invasives or administer noxious weed control programs on ROWs and perform work through local weed and pest districts. These approaches may vary by district.
- ODOT designated District Vegetation Management Coordinators as the primary staff for noxious weed control. Additional staffing is done on a case-by-case basis.
- WSDOT hired an IRVM program manager for part of the state, appointed an IVM lead technical specialist in maintenance for some areas, and hired a state horticulturist and a new statewide roadside specialist.
- The U.S. Forest Service contracts out some invasives control and does other work through force accounts.

Overall, private contract forces are used for some weed control by 43% of responding DOTs. Private contract forces perform all weed control at 15% of responding DOTs. Some weed control is contracted out or otherwise done by cities and counties in the case of 13 DOTs (33% of respondents). State forces handle all weed control for one-quarter of all DOTs (12 states). Partnerships with private landowners help accomplish invasive species control adjacent to the ROW in the case of 25% of responding DOTs. A similar percentage partner with nonprofit or nongovernmental conservation groups. Off ROW areas are maintained by four responding DOTs (10% of respondents). ODOT has been active with Cooperative Weed Management Areas (CWMAs) across the state. The CWMAs are comprised of government organizations, private landowners, and nonprofit and nongovernmental conservation groups, with the goal of controlling invasive plant species by combining efforts, resources, and knowledge.

INVOLVEMENT OF VARIOUS DEPARTMENT OF TRANSPORTATION BRANCHES AND DIVISIONS

Invasive species control involves a cross section of DOT professionals. Some state DOTs, such as Caltrans, have implemented interdisciplinary teams at the district level to address the corridor-specific needs and site-specific challenges of invasive species control.

Invasive Species Management

At DOTs, the maintenance division is most commonly involved in invasive species management (93% of all responding DOTs). Construction is involved in invasive species management at approximately one-half of DOTs.

- Review and specification of seed mixes (Arkansas).
- Development of a compliance checklist for stormwater and seeding, and development of new sections in the construction manual, to be followed by training (Arizona).
- Development of special provisions (Arizona).
- Development of standard specifications requiring sod, seed, mulch, and soils to be free of invasive plants and plant parts (Florida).
- Implementing and enforcing specifications developed by design staff, administering contracts (California, Iowa, and Minnesota), and managing plant establishment (Washington State).
- Overseeing contractors when removing invasives during construction and adherence to BMPs (Connecticut, Nevada, New Mexico, Pennsylvania, Rhode Island, and Wyoming).
- Isolating and often burying invasive species (Maryland and Missouri).
- Minimizing disturbance of roadsides, including native seeds in revegetation, and including topsoil when and where needed (Montana).
- Performing revegetation training for construction inspectors to ensure quality control (Texas).

On a daily basis the maintenance staff is on the front lines of invasive species management on roadsides. They have been involved in a variety of ways:

- Mowing, spraying, and vegetation removal (all DOTs).
- Identification and control methods are routinely discussed in annual vegetation management classes conducted by the Maintenance Bureau (Alabama).
- Development and distribution of identification charts to all district offices throughout the state (Alabama).
- Detection and control of high-risk invasives (Hawaii and Louisiana) and development of databases with locations of priority invasive species in the ROW (Alabama, Colorado, Montana, and New Mexico), and monitoring existing populations (Missouri).
- Development of control programs for specific invasive species and locations in each district (Alabama, Florida, and Wisconsin).
- Development of a Roadside Vegetation Management Handbook, with district input (New Mexico).
- Maintenance of a vegetation management website, providing the public with spraying and mowing schedules (New Mexico).
- Lead implementation of invasive species eradication, including seed head suppression with herbicides, no mow policy when seed is present, and education of personnel for identification (Maryland, Minnesota, and Missouri) and on a limited basis stressing or providing support for weed eradication before construction (Minnesota).
- Development and implementation of the DOT's IVM plan (Alabama, Arizona, Arkansas, Iowa, Minnesota, New York, and Washington State), including identification and management of environmentally sensitive areas (California, North Carolina, Oregon, and Texas) and prioritizing resources and treating weeds accordingly (Iowa).
- Conducting in-house training on species identification, mapping, and potential control methods (Arizona, Colorado, Maryland, Texas, West Virginia, and U.S. Forest Service).
- Distribution of funds to counties for spraying and IVM and weed control (Maryland, Wisconsin, and Wyoming).
- Addition of language on invasive species to specifications (Hawaii).
- Coordination with state DOA and Invasive Species Councils to detect and treat invasions (Hawaii, Maryland, and Wyoming).
- Testing of herbicides to develop BMPs for herbicide control (Mississippi).

Design and Project Development Staff

Design staff is involved in invasive species prevention and control efforts in 58% of responding DOTs such as:

- Design and specification of seed mixes (Arkansas, Colorado, Iowa, and Nebraska) for erosion control and revegetation. Ensuring use of native or adapted species and compost in design (Texas and Washington State).
- Requiring weed-free mulch on projects (Nebraska).
- Development of guidelines for projects on U.S. Forest Service and BLM lands; establishing policy for design, construction, and maintenance (Arizona).
- Landscape architect development of construction plans, project-specific invasive species control strategies, and specifications (Arizona, Colorado, Iowa, and New Mexico).
- Identifying invasives to be removed on projects during construction (Connecticut).
- Attendance at courses by and coordination with the University Extension Service, DOA, and others (Arizona).
- Development of Roadside Toolbox of specifications, tools, guidance (California) and Design Manual guidelines (Pennsylvania).
- Performing research to develop methods for better success of installing and establishing native vegetation (California).
- Developing, implementing, and overseeing landscape plan preparation requirements, including prohibition of plants known to be invasive and notation of existing patches of invasive species on plans, so the latter can be

properly removed and disposed of during construction (Florida).
- Adding language on introduction of invasives to existing specifications (Hawaii).
- Administering vegetation management program, design of seed mixes, design of erosion control projects, and specifications, coordinating statewide seed and herbicide purchases (Iowa).
- Developing Statewide Landscape Master Plan, including invasive species element (Nevada).
- Removing invasives as part of landscape projects (Rhode Island).

Project development sections have been involved in:

- Project-by-project mapping and assessment (California).
- Preparation of invasive species sections of EAs and EISs (Iowa).
- Incorporation of invasive species components into Highway Project Development Process Guidelines (Minnesota).
- Implementing principles of the state's IVM and Roadside Classification Plan (Washington State).

Support by Planning and Environmental Sections

Planning and project development continue to be involved most infrequently; just 25% and 20% of responding DOTs, respectively, involve these sections in IVM, despite the recent changes imposed by E.O. 13112. Where planning and environmental sections have been involved, they have supported:

- Early weed surveys (Arizona).
- Project review for invasives and incorporation of weed removal as project mitigation (Connecticut) and for addressing invasives in NEPA documents (multiple).
- Seeding recommendations for all projects (Colorado and Wyoming).
- Development of policy to control all invasive species on the state highway ROW (Nebraska) or agency-wide guidance (Ohio).

Management Involvement Can Propel Invasive Species Control Efforts

Upper levels of management are infrequently involved in invasive species control efforts; just seven DOTs (18% of those responding) indicated they were. Where management is involved, they write policy related to vegetation management (Iowa); develop agency-wide business plans and performance measures (Maryland); or identify funding, priorities, and personnel assignments (Minnesota). At NCDOT, "management is very aware of the need to control invasive plants and the potential problems associated with a lack of control. Management, when appropriate, reiterates the need for funding to help control these invasive plants." Top management support of initiatives at WSDOT has helped drive invasive species control. At WisDOT, for several years, the Central Office Bureau of Highway Operations sponsored a budget initiative that allotted $400,000 to supplement the funds that each district budgeted for noxious weed control. Unfortunately, owing to severe funding limitations, districts budgets were drastically reduced and the initiative was dropped.

Dedicated Annual Budget for Control of Invasives

DOT maintenance divisions often receive no special budget allocation for invasive species. Spending on invasives ranged from very little to $10 million annually at PennDOT and $15 million at TxDOT on chemical vegetation control.

At least 75% of all DOTs (88% of those responding, or 35 DOTs) have no annual budget for control of invasive species; all expenditures come from general maintenance funds. Only six DOTs (15%) reported specifically budgeting for IRVM or control of invasive species. Sometimes special allocations have occurred, as in Colorado, from the Transportation Commission, or in Wisconsin, from the Central Office Bureau of Highway Operations. Enhancement projects have also included funding for control of invasive species. In Iowa, some project funds are used to purchase materials for invasive species control in the project area by maintenance forces, before and after the project.

Pressing safety-related maintenance needs such as snow and ice control often prevail over invasive species control in tight budgets. Some DOTs have estimated the amount of their total herbicide budgets where the product was purchased specifically for the control of invasive species; MoDOT estimated approximately 30%. In 2004, NYSDOT began requiring each district to redirect a portion of their operating funds to environmental stewardship activities, of which invasive species control was a primary activity.

Plans, Geographic Information Systems, Research, Posters, Guidance, Fact Sheets, Signs, Tours, Personal Contact, Training, and Field Resources

DOTs are taking a variety of steps to share information across division areas and professional specialties, to address cross-cutting needs, and to take a more integrated approach. Information is often exchanged informally; however, foremost among the more formal approaches are the development of organization-wide and district-specific IVM plans and GIS systems with locations of weed patches and the ability to track and assess treatments. Also common are the creation of informational posters and laminated field materials (17 DOTs, 43%). Seven DOTs have developed and distributed newsletters or fact sheets on invasive species control. In addition, seven DOTs have developed summer field tours for roadside

and maintenance staff to build awareness, share roadside research and field findings, and for districts to compare control programs. DOT landscape architects and IRVM managers have also developed session topics at statewide annual environmental, construction, and maintenance meetings. Other communication activities include:

- Meetings across functional areas, specifically environmental, project development, and maintenance meetings.
- Participation in conferences.
- Cooperation with design on producing permanent vegetation control features and better designs to reduce the need for continuous vegetation control.
- Creation of videos and training materials.
- Outreach to and by landscape architects and parts of the organization involved in land management. Training workshops open to and attended by other agencies. Attendance in regional workshops, with other states. Coordination among landscape architects and with universities.
- Increasing involvement of maintenance in construction and project development review.
- Orientation, reminders, and signage of environmentally sensitive areas in the ROW.
- Inclusion of a chapter on invasive species in guidance manuals related to the environment, construction, and maintenance.
- Development of an agency-wide work group with representation from all regions and functional groups.
- Establishment of an electronic web space or information sharing group to promote communication, updates on outbreaks, and information exchange and technology transfer.
- Annual research reports geared to each field.

Particular state communication efforts have included:

- Formation of an Invasive Species Work Group with representatives from all regions and main office functional groups, accompanied by an Invasive Species Web Board to foster intra- and inter-agency communication and information exchange (New York).
- Active DOT leadership in establishing a state Vegetation Management Association, creating a cooperative effort between utilities, cities, municipalities, university researchers, manufacturers, and distributors. Various DOT managers are active on the board of directors (North Carolina).
- DOT hosts a Local Training Assistance Program every year that shares what the DOT is doing with other local public agencies (Ohio).
- Publication of an annual Roadside newsletter, fact sheets, and annual research reports, through printed and electronic means of information sharing (Pennsylvania).
- Annual summer roadside field tour displaying techniques and strategies to control invasive species to roadside and maintenance personnel. The winter and summer roadside vegetation management training sessions provide educational and brainstorming opportunities for roadside personnel (Pennsylvania).
- Performance of a "tremendous amount of research, both in-house and contracted, on invasive control, plant establishment, and plant selection" (Texas).
- Development of technical manuals for roadside maintenance, landscaping, seeding, control of invasive species, and establishment of native plants (Minnesota, North Carolina, Pennsylvania, Vermont, and Wisconsin).
- Use of Internet and intranet, articles in agency quarterly reports, internal roadside meetings and conferences (New York and Wisconsin).
- Strong central coordination through the DOT's state agronomist. State agronomist and maintenance program work closely with the noxious weed program. Field maintenance personnel communicate through the agronomist for any seeding recommendations and setting up products for district broadleaf and growth retardant programs. The agronomist and maintenance program are working with construction and are starting to set up additional training with Wyoming DOA to review pretreatment of proposed construction zones and gravel sources (Wyoming).
- National Invasives Species Issue Team meets monthly. The team includes a staff director from the National Forest System Deputy Area, a staff director from the Research Deputy Area, and a staff director from State and Private Forestry Deputy Area. There are numerous staff people from the deputy areas on the team (U.S. Forest Service).

Greater Funding, Higher Level Support, and Awareness Could Help Control Invasives

DOTs also identified what their agencies were not doing to help control invasives. To help accomplish these objectives, DOTs suggested:

- Making invasive species control a priority. Having a clear commitment or policy by upper management and consistent funding.
- Decision making and planning needs to be at a director's level or higher.
- Determining actual harm to human health, natural areas, native plant communities, or economic considerations in state ROW from invasive species to influence decision makers.
- Fostering awareness of E.O. 13112 by management and communication of the department's policy or intent to staff.
- Having transportation engineers responsible for the decision-making process and policy adjustments at all levels attend annual meetings of the National Roadside Vegetation Managers Association.
- Addressing specific funding to invasives control. Dedicating staff and resources to address the growing problem.

- Allocating sufficient resources and equipment to time mowing when it could be most effective for invasive species control, rather than when resources and equipment are available, or as close as can be achieved with the resources the agency has.
- Training for maintenance mowing crews and for construction inspectors.
- Expanding the list of invasive species for location, monitoring, and treatment.
- Providing a separate budget item for invasive control and inventory of area infestation.
- Developing an understanding of what invasives are and what impact they are having.

Greater Attention During Construction Could Reduce Long-Term Maintenance Problems

As found in WSDOT's value engineering research, greater attention to pretreatment of construction sites and materials source, as well as more resources and inspection support for establishment of native vegetation, could substantially reduce long-term maintenance costs. DOTs identified the following as activities they believed would make the most difference, but that were receiving inadequate attention:

- Providing more attention to monitoring of construction sites.
- Restricting aggregate sources for construction projects and ensuring that contractors are working closely with local weed districts before beginning work.
- Disturbing less roadside area and being more active in managing topsoil or ensuring quality soil placement on our roadsides to grow the kinds of vegetation we desire.
- Establishing a program based on roadside acreage, amount of invasive species, and funding to implement the program and then monitoring results on whether one is gaining or losing ground—is the program successful?
- Better inventory of priority species and a much broader and consistent approach to implementing controls and identification of more detailed priorities by geographic regions. Tracking populations of invasive and noxious weeds so that spray contracts can be developed that are more accurate in their application.
- Increasing focus and funding for seeding competitive groundcovers.
- Developing weed and vegetation management goals and objectives. Developing formalized plan for removal of invasives; in particular, have a statewide plan of attack for top five invasives.
- Better coordination of areas and weed mapping.
- Having someone in each district whose position is devoted to vegetation management.
- Incentives and educational programs to the adjacent land owners; grants or additional budget items to control invasive plants on private land.
- Including invasive species components in the federal funding review process for new projects.
- Shifting efforts from trying to control the uncontrollable species listed in state statutes, which are primarily agricultural weeds, to controlling new invasives before they become uncontrollable; that is, early detection and rapid response.
- Developing procedures in preliminary field engineering guidelines to make contact with local weed and pest districts to ensure that project areas and gravel sources are reviewed and treated before soil disturbance. Making sure this process is used on a regular basis.

FINDING ASSISTANCE AND TECHNICAL SUPPORT

DOTs draw on internal as well as external resources when seeking assistance and technical support, and to make concrete progress toward control of invasives. Figure 8 illustrates the range of different sources DOTs use and the percentage of respondents using those sources.

Department of Transportation Maintenance, Construction, and Landscape Architects

When asked which sections of their organization needed assistance, all parts of the organization were mentioned as needing more support:

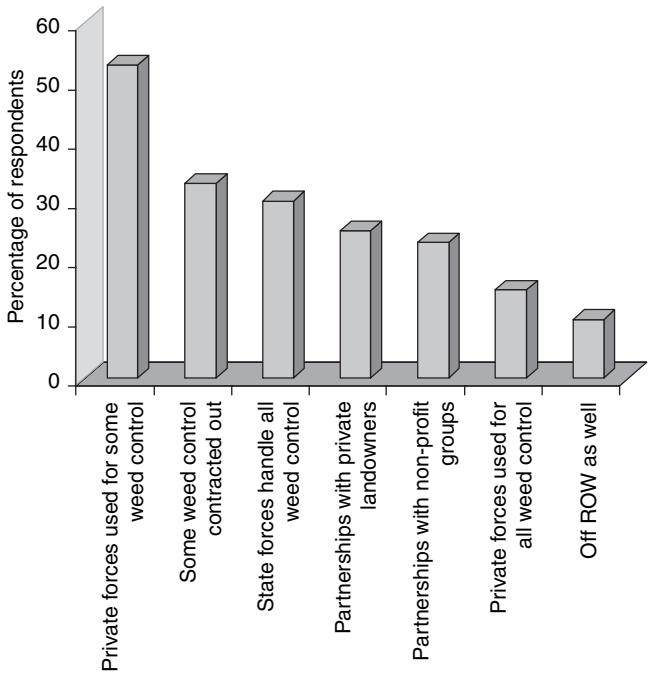

FIGURE 8 Department of transportation work force mix for invasive species control.

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- Design engineers and environmental analysts,
- Biological input/support in construction and maintenance,
- Landscape architects and landscape supervisors,
- Erosion engineers, and
- Maintenance staff.

Maintenance was mentioned most often as needing support, with landscape architects and construction staff mentioned next most often. Public agencies managing invasive species and/or public lands have been advised to provide proficient weed management expertise at each administrative unit; expertise means that necessary skills are available and corporate knowledge is maintained.

When asked what would help staff who needed further support, DOTs mentioned the following:

- More resources, funds, and full-time employees for invasive species; the maintenance and construction costs of landscaping; and to identify and treat outbreaks.
- Awareness and training on species identification and management.
- Training and funding to conduct controlled burns to accelerate prairie establishment and maintenance.
- Certified personnel available to conduct spray programs.
- Research, because the agency is "still experimenting with seed mix prescriptions to determine what works where."
- Lists of salt and pollution-tolerant plants.
- Comprehensive/integrated (re)vegetation management plan(s).
- Additional training on the state of the practice.
- Training on revegetation practices.
- Vegetation management support in each district and region office.
- Clearinghouse that provides information on native seed suppliers and the latest research.
- Contact information of other DOT personnel for networking.

Other needs that were identified included "the freedom to approach problems proactively rather than only reactively" and "directives to do what the E.O. requires."

Other Agencies and Universities Offer Technical Support

When in need of assistance regarding invasive species control and restoration, more than three-quarters of invasive species leaders at DOTs go to other agencies or to universities; the latter most often perform testing and studies (see Figure 9). Chemical company representatives also offer assistance; 68% of responding DOTs turn to them. Other DOTs are a resource for more than half (60%) of DOTs. Program leaders also find what they can on the Internet (50% of respondents). County weed personnel are contacted for information or assistance by more than one-third

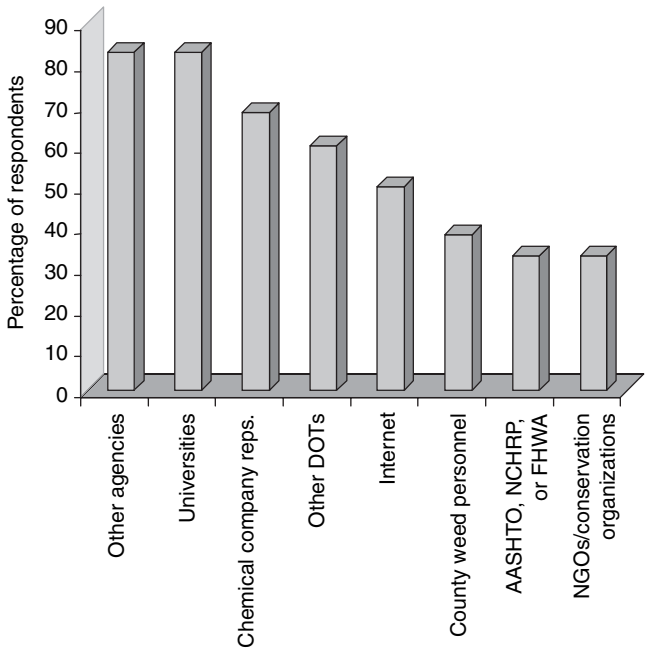

FIGURE 9 DOT information sources for invasive species control.

of all state DOTs (38% of respondents), whereas AASHTO, FHWA, and NCHRP are contacted by 33%. Nongovernmental organizations (NGOs) or conservation organizations served as resources to a similar percentage (33%) of DOTs. Interagency weed management groups, vegetation management associations, and mowing and brush cutting equipment distributors also provide support.

PARTNERSHIPS IDENTIFY AND CONTROL NEW AND EXISTING POPULATIONS

Eighty-five percent of responding DOTs (34 states) are working with others outside the agency to identify existing or emerging populations of invasives. Just 10% said they were not. State DOTs are working with WMAs, regional associations and councils, other federal and state land management agencies, and entities that may be able to provide technical support or concrete assistance like agriculture departments, U.S. Geological Survey, and various NGOs. Figure 10 shows some of the most common partnerships.

State Invasive Species Councils or Task Forces Are Most Common Partnership

The most common DOT partnerships for invasive species control are DOT participation on State Invasive Species Councils/Task Forces or state noxious weed committees (25 DOTs, 63% of total responding). More than 40% of DOTs (17) partner with universities to conduct research. Western states comprise most of the 25% of DOTs that partner with local WMAs. Ten states (25% of responding DOTs) address invasive species issues through watershed planning efforts.

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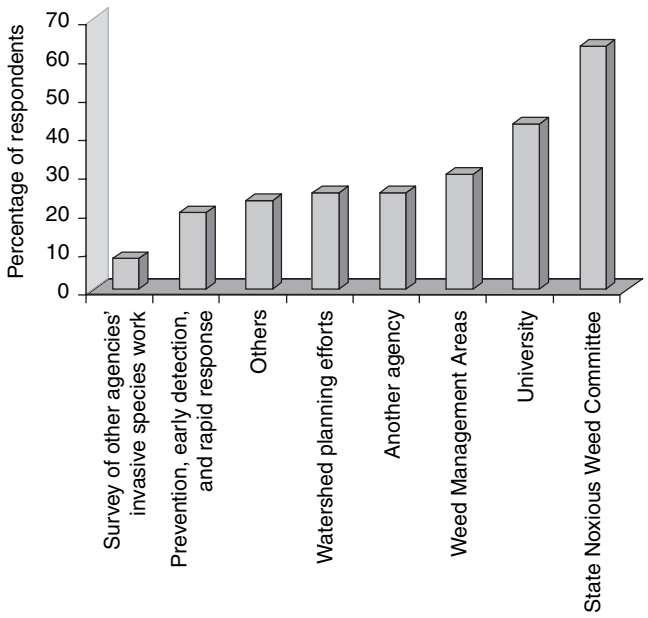

FIGURE 10 DOT partnerships for invasive species control.

Three DOTs have conducted a survey of other agencies and organizations' invasive species work, approaches, or priorities. Other partnerships include those with:

- Herbicide manufacturers and vendors in test plots to find control options.
- Universities on research on specific control methods.
- Weed control associations on the state or regional level.
- Local weed district and WMAs.
- The Nature Conservancy to control weeds in the ROW and work with landowners of adjacent properties and natural areas.

Partnerships with Other Agencies

Twenty-five percent of responding DOTs work with another agency to have them review and treat the ROWs. For example, Hawaii DOT has the state DOA and Invasive Species Council handle high-risk invasives. WYDOT and NDOT administer noxious weed control programs on ROWs through their state DOAs and perform work through local weed and pest districts. Maryland State Highway Administration, New Hampshire DOT, and ODOT also work with their state DOAs to have them review and treat the ROW. Caltrans does the same with county agricultural commissioners, as does Alaska Department of Transportation and Public Facilities with its DNR Plant Materials Center. Eight DOTs (20% of respondents) participate in prevention, early detection, and rapid response and inventory programs with other agencies or organizations.

In addition to its statewide focus on four priority invasive species, NYSDOT is a key partner in the APIPP. Five partners are cooperating agencies: NYSDOT, Invasive Plant Council of New York State, Adirondack Nature Conservancy, New York State Adirondack Park Agency, and New York Department of Environmental Conservation. The agencies share an MOU for advancing regional, coordinated invasive plant species initiatives under the umbrella of the APIPP. Private landowners, local communities, and volunteers also participate and keep track of and take action to control invasive aquatic and terrestrial plants. With few access routes, the Adirondacks are one place in New York where preventative measures to control invasive species can be taken *before* widespread infestations are established. Priority aquatic species for the partners include Eurasian watermilfoil, water chestnut, and curlyleaf pondweed. Purple loosestrife, Japanese knotweed, common reed, and garlic mustard are on its terrestrial list. These species have been found to affect native plant and wildlife populations; impair recreational access to and use of land and waterways; reduce property values; negatively affect tourism, fishing, and boating opportunities; are easily spread by human activities; and are extremely difficult and costly to remove (*115*).

NYSDOT's role in the APIPP is outlined in the interagency MOU and includes the following (*116*):

- Conducts control activities within Interstate and state highway ROWs.
- With the appropriate releases, conducts control activities on private lands adjacent to the department's ROW.
- Collects requested data regarding location, species, and control methods.
- Develops guidance, specifications, training materials, and BMPs that reduce or eliminate the introduction and spread of invasive species within the ROWs.
- Utilizes species location information for BMPs when designing, constructing, and maintaining Interstate and state highway systems within the park.
- Seeks continued federal funding for research on invasive plant management issues.
- Develops a written annual work schedule committing to invasive plant species management within the ROWs in the park at the annual late winter partners' meeting.
- Provides status reports regarding the previous item at the annual summer and early winter partners' meetings.
- Provides invasive plant species awareness and management training to appropriate state DOT staff.
- Identifies invasive plant biomass disposal and transfer areas at local residencies and other department-controlled facilities.
- Coordinates with local municipal maintenance and transportation departments on highway BMPs that would be implemented on nonstate highways and roads.
- Assists maintenance of Terrestrial Invasive Plant Project database: documents new infestations, documents management controls implemented on existing

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infestations, and produces maps for APIPP website and participants.

Some DOTs indicated that their partnerships are currently limited; however, that they anticipate a more active exchange with other agencies, the U.S. Forest Service, and tribal lands in the future. Coordination actions form components of the state DOT's IVM plan in Montana. Links to state organizations with an interest in the prevention, control, or eradication of invasive species are available on-line.

Partnerships with Nongovernmental Organizations and Quasi-Governmental Organizations

Approximately one-quarter of DOTs turn to NGOs or conservation organizations when in need of assistance. Links to professional and nonprofit organizations with an interest in invasive species control are available on-line. State NHPs are available through NatureServe's website.

DOTs indicated that they are working with the following NGOs and quasi-governmental organizations:

- WMAs;
- Statewide committees for noxious weed management;
- State NHPs;
- Universities and extension services;
- The Nature Conservancy;
- Native plant and wildflower societies;
- Crop Improvement Associations, to provide the DOT with quality assurance for yellow tag native seed and certified weed-free mulch; and
- Local working groups and restoration enthusiasts.

A number of innovative partnerships have been developed. Some of the most well-known are those with The Nature Conservancy; in particular, NYSDOT's APIPP program. In the environmentally sensitive Adirondack Park, NYSDOT regional maintenance staff, the Adirondack Park Agency, and the Adirondack Chapter of The Nature Conservancy have jointly initiated a demonstration knotweed control program. The pilot demonstration project involves hand cutting individual knotweed plants, properly disposing of the harvested plants, and using NYSDOT-certified herbicide applicators to swab the residual cut knotweed stems. This project incorporates a training component by inviting local Department of Public Works maintenance workers and resource agency staff to observe and participate.

Partnerships with Weed Management Areas or Districts

Some agencies, such as Arizona DOT, rely extensively on weed management districts or areas and cite work with these entities as one of their most effective strategies for controlling invasive species. One reason supplied was the DOT's "lack of funding, resources, and commitment." Caltrans, for example, relies on local WMAs to identify areas of focus so that limited resources can be combined. NDOT uses established weed districts' labor and materials on a reimbursable, for spraying agency ROWs. NDOT provides Weed Management Associations with a contact at the agency. NYSDOT relies heavily on Weed Management Associations and calls them "the best example of a Landscape-Level approach to invasive plant management" in the state. ODOT is involved with the Jordan Valley Partnership, a combination of county, state, and federal agencies that pooled resources to control vegetation that has been very successful and in place for several years. WYDOT relies heavily on its DOA and County Weed and Pest districts for invasives identification, inventory, and treatment, in addition to participating with some local WMAs through WYDOT district staff. Iowa DOT maintains communication with county and state weed commissioners, the extension service, and the DNR when finding new invasive weeds. WSDOT is involved with state and local weed boards. Other DOTs cooperate more occasionally with Weed Management Associations with or partners with them little or not at all. A number of DOTs are aware of only one or none in their state.

Benefits of Partnerships with Weed Management Areas and Districts

DOTs identified a large number of benefits with partnerships with WMAs and districts.

- Outreach and education;
- Maximal use of resources (funding, personnel, and equipment) and coordination of efforts for the highest priorities in the area;
- Control of infestations that cross property lines;
- Knowledge, expertise, networking, common goals, synergy, and relationship building; and
- Risk taking.

Nevada noted that most of the counties in the state do not have staff available to provide control measures and therefore the Weed Management Associations help fill in the gap.

Challenges in Working with Weed Management Areas and Districts

Many DOTs noted that the lack of focus derived from too many groups, lists, and different agendas has diffused the effectiveness of partnering with WMAs and districts. In some areas, the goals of the Noxious Weed District, may be different than that of the transportation agencies. The most commonly cited limitation with such partnerships was a lack of adequate resources; DOTs were often viewed as

having the most to contribute. However, local weed lists are particularly important in states such as California, with notable climate gradations within small areas.

According to research for the NISC, all groups established to address early detection and rapid response to invasive species should have clear, unique goals and lines of communication to and support for field activities (*18*). Proliferating groups, committees, task forces, etc., may find it difficult to avoid redundancy and spending undue time on coordination. The fire management system provides a useful model where there is a central "backbone" system with clearly related, hierarchical tiers; all working groups, boards, teams, etc., have clear relationships with the central backbone and its function (*18*). Information management, funding, and interagency coordination are all aspects that benefit from central coordination.

Considering and Incorporating Local Weed Lists

States or other areas with diverse climates and geology often require local lists of invasive species. DOTs had a number of suggestions for how to consider and incorporate local weed lists without getting bogged down:

- Prioritize.
- Maintain a local focus; base district efforts on local priorities. At the other end of the spectrum, "don't incorporate local lists unless definitive research has been done to show the harmful effects of the plant to roadsides."
- Eliminate invasives from DOT plant lists.
- "We try to honor requests but we are only required to control the 11 plants on the state prohibited noxious weed list. Some counties elevate weeds from the state secondary list to prohibited noxious weed status by County Board action."
- Keep a common list available, posted, and current or just consider local lists as guidance.

A few DOTs have opted not to incorporate local weed lists within the agency's list of priorities. One DOT noted that a drawback of many lists, "which are more or less different people's perceived invasives lists," is the confusion and resistance that they can create in the landscape industry. Some DOTs have opted to only use the state noxious weed lists issued by the state DOA or other official list maintained by the state. These lists frequently focus on agricultural weeds rather than a broader set of invasive species. Lists issued by statewide invasive species control councils, also used by DOTs, may be more inclusive.

Sample Department of Transportation Cooperative Efforts with Weed Management Areas and Districts

State DOTs can cite a variety of cooperative efforts with WMAs and districts.

Caltrans Partnerships with Weed Management Districts

Caltrans partnerships with weed management districts are sometimes formalized in agreements, which oblige Caltrans to perform actions such as the following:

- Educate Caltrans employees about noxious weeds, their identification, methods of control, and prevention.
- When available, provide data on noxious weed infestations on Caltrans ROWs property to the County Agricultural Commissioner's Office.
- Identify high-risk pathways of noxious weed introduction onto Caltrans-maintained roads and highways.
- Promote and implement elements of integrated weed management to prevent the establishment and spread of noxious weeds in the county or district.
- Cooperate with agencies and landowners in joint programs and projects to prevent, control, and eradicate noxious weeds.
- Provide assistance with grant proposals to fund noxious weed control programs.

WYDOT MOU with Agriculture Department and County Weed and Pest Districts

By 2001, WYDOT had inspected 95% of all state and federal centerlane-miles for invasive species, the result of an effort begun in 1985 as an MOU with the state Agriculture Department and County Weed and Pest Districts to control invasives in public ROWs. The inspection and tracking effort resulted in the spraying of 4,600 ROW acres and the use of native, competitive plants for revegetation since 1991. WYDOT has required certified mulches on construction projects since 1986, a proactive approach that has saved significant funds (*76*).

Coordinated WMAs in New Mexico

In 2001, New Mexico Highway and Transportation Department and 32 other groups signed an MOU requesting that all levels of land managers participate and support CWMAs covering the state. The signatories of the agreement jointly inventory, manage, prevent, and eradicate whenever possible, plants designated as noxious pursuant to the New Mexico Noxious Weed Management Act of 1978, using the New Mexico Strategic Plan for Managing Invasive species, as a basis for coordination. New Mexico built on the experiences of Idaho, Montana, Wyoming, and the Dakotas. New Mexico Highway and Transportation Department implements Noxious Weed Management Plans for individual projects and is reviewing maintenance strategies to further improve its weed reduction efforts.

Partnerships with Private Landowners

State DOTs have a number of mechanisms for partnering with private landowners; however, an informal "good neighbor" policy with adjacent landowners is the most common. Often, the DOT will advise a landowner when we are treating an invasive so that they may take action at the same time (Mississippi). Some landowners request no-spray zones that the DOT honors as long as the landowners fulfill their agreement to control the prohibited invasive species in these areas (Minnesota).

Cooperative Efforts Across State Lines

Approximately one-third of all DOTs (15 states) reported that they were involved in cooperative efforts across state lines. Examples of these efforts include the following:

- Mississippi is spearheading a regional invasive species alliance in which Alabama DOT will be participating.
- Research funding of biological control for various invasive species (California).
- Multistate, multiagency coordination effort for prioritizing and mapping Sahara mustard (California).
- Sharing news regarding new invasives, priority invasives, and treatment (Alabama, Arkansas, Colorado, Connecticut, Louisiana, Mississippi, Missouri, New Hampshire, Tennessee, Texas, and Utah).
- Participation in cross-border councils and/or annual conferences (New Mexico, Pennsylvania, Utah, Washington State, Wisconsin).
- Working on a reciprocal agreement on the use of certified weed-free mulch to expand the market and make it more attractive for producers (Illinois, Iowa, Minnesota, and Wisconsin).
- Partnering international organizations may be located on-line.

The Chesapeake Bay Watershed Commission and Delaware Basin are examples of other widely known multistate efforts.

Department of Transportation Partnerships with Utilities

Recently, NCDOT began working cooperatively with the North Carolina Department of Agriculture and Consumer Services Agronomic Division and utility companies to eradicate a site of purple loosestrife found on a utility easement that crossed the DOT ROW. This initiative is on-going as annual inspection tours are conducted to control any newly germinated seed.

Utility companies have also pioneered no-spray agreements with landowners, which have been models for DOTs. In the summer of 1998, utility companies in North Carolina reached a private agreement with landowners regarding management of their 75,000 miles of ROWs. The agreement, which does not have the force of regulation, was sparked by complaints to the state pesticide board regarding the North Carolina utility companies decision to begin broadcast spraying of their ROWs. Organic farmers and people concerned over the use of herbicide demanded that the state pesticide board require the utilities to request permission from landowners to spray herbicides on adjacent ROWs. The state pesticide board asked the utilities and complainants to sit down together and devise an agreement among themselves. The final agreement, accepted by all parties, with petitioners represented by the Agricultural Resources Center, requires utilities to include inserts about their herbicide use in customer bills. The inserts include the names and descriptions of the chemicals, how they are applied, and sources for additional information about the applications. The inserts do not disclose spray schedules. The agreement also gives state residents the right to refuse herbicide use on their property, and individuals can post their property with no spraying signs provided by the utilities. For those opting for no-spray agreements, the utilities will still maintain the ROW by mechanical means without extra charge to the individual landowner. Carolina Power & Light voluntarily sends notices to its customers in South Carolina regarding ROW herbicide applications as well (*117*).

BLM, U.S. Forest Service, FWS, and National Park Service are currently working with the Edison Electric Institute to develop an MOU for vegetation treatments along utility corridors.

DEALING WITH PRIVATE PROPERTY ISSUES

As indicated in Figure 11, when asked how their agency deals with private property issues and invasives or noxious

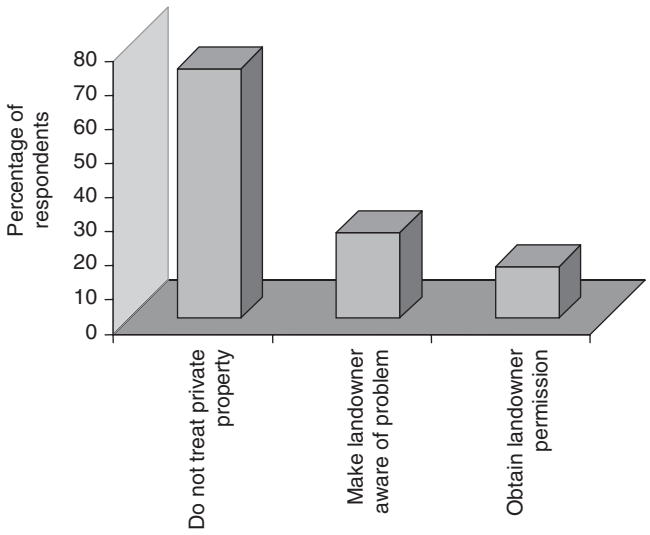

FIGURE 11 Private property treatment.

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weed control, nearly three-quarters of the responding DOTs (29 states) stated that they do not treat private property; however, 25% of responding state DOTs will make landowners aware of any problems and inform them of other resources and programs to assist them. Six DOTs (15%) have on occasion obtained landowner permission to control invasives on properties adjacent to the ROW.

NCDOT is one of those that noted that it will work cooperatively with private landowners on request. Some DOTs noted that they rely on Weed Management Associations and volunteer groups to coordinate with property owners. Others do their best to cooperate with adjacent landowners; one said, "[i]f our 'good neighbors' are trying to control invasive—we try to help them out on our side of the fence." WYDOT noted that their agency will treat private lands where the agency has easements for snow fence, materials, or borrow areas. On occasion, NYSDOT has obtained written landowner releases to control invasive plant populations that have spread beyond the DOT ROW. Not having up-to-date statewide invasive species inventory information limits the prioritization of management activities by NYSDOT because coordination with control efforts by others adjacent or nearby to ROW is hampered. When a DOT cannot treat private property and no noxious weed law compels private landowners to control invasives on their property, some agencies noted that it does little good to control the invasives on the ROW. WisDOT has resolved the problem by only controlling weeds where the landowner is controlling them on his or her side of the fence, to concentrate resources where they will do the most good. This has worked because WisDOT's control efforts are currently directed at weeds that are primarily agricultural.

OBSTACLES TO EFFECTIVE COORDINATION

The decentralized approach to invasive species control is one of the biggest obstacles to effective coordination and control of invasives. A patchwork of different state and local laws and shifting state administration priorities or level of emphasis on invasive species control complicates both controlling the invasives and working with one another, despite the benefit of faster communication mechanisms.

In July 2001, the GAO reported to Congress on various obstacles to federal rapid responses to the growing threat of invasive species (*118*). GAO found that, in general, species that threaten agricultural crops or livestock have elicited a faster response than those affecting forestry, rangelands, aquatic areas, or natural areas. More than 20 federal agencies have responsibility for some aspect of invasive species management. Invasive species are not specifically identified in the missions of many agencies. Within the Departments of Agriculture and Interior that have these missions, many priorities compete for scarce resources.

According to GAO, the major obstacle to rapid response is the lack of a national system to address invasive species. Other factors involved included (*118*):

- Federal agency funding and authorities vary;
- Federal response to invasives that threaten natural areas has been minimal;
- APHIS does the most rapid response, focusing on crops and livestock;
- Invasives that threaten natural areas receive less funds than those that threaten crops and livestock;
- Where rapid response has not occurred, costly consequences follow;
- Additional detection systems are needed for earlier identification;
- Stronger federal, state, and local partnerships can help;
- Enhanced technologies and additional research are needed; and
- Rapid response depends on the centrality of invasive species to an agency's mission.

Because many agencies do not have responsibility or mission for rapid response, the report suggests that a coordinated approach nationwide is needed to ensure that invasive species get a level of attention commensurate with their risks. The NISC agreed with GAO and new emphasis is being placed on that area. The Department of Homeland Security has recently joined NISC, and FWS now leads the Aquatic Nuisance Species Task Force.

Departments of Transportation Identify Their Primary Coordination Obstacles

The 40 state DOTs that participated in this research identified a number of obstacles in their attempts to coordinate with others to achieve effective invasive species control.

- Lack of authority outside the ROW and treatment of invasive plants only within the ROW. Acquiring a complete list of representative species and working with private landowners to spray their fence lines adjacent to DOT ROWs. Uncooperative landowners, absentee landowners, etc.
- Permit requirements and liability issues if others work on ROW.
- Communication and varying priorities among different agencies. Assessment of weeds, perception of different species, politics, and personalities.
- Who to coordinate with, different inventory approaches, and accuracies.
- Inadequate internal expertise.
- Lack of a statewide plan.
- Few agencies have a dedicated invasive species contact person.
- Lack of dedicated funding hampers follow-up.
- Many of the meetings occur outside of normal work times so it is difficult for employees to attend.

- Very little assistance is available from others to control invasive species.
- Public awareness.

Departments of Transportation Recommended Solutions

DOTs recommended the following to help address the challenges they identified previously:

- Formal statewide IVM plan and weed management policies. A master plan reflecting consensus on strategy, mapping protocol, inventory, and dollars to implement the plan.
- More certainty with the long-term direction of the state invasive species council.
- Someone in each district whose position is dedicated to vegetation management.
- Faster response from upper management with go-ahead to carry out staff's ideas.
- Increased resources—dollars, equipment, personnel, especially federal funding.
- Increased emphasis by upper management and/or a state executive order.
- Creation of state weed lists where none currently exist.
- Public education.
- Incentives.
- A statewide weed board with fines for noncompliance.
- Money to buy herbicides for the private landowner, as is done in some states. Source would most likely be DOA.

DOT recommendations regarding successful, efficient strategies for coordinating with others include the following:

- Participate actively in groups. Network and have open communications.
- Establish a leader.
- Focus on common issues and "work the best you can around the funding."
- Provide a place for "one stop shopping" for communication and information sharing on the state level.
- Communicate with all groups. Have a local DOT representative participate in the local weed management group.
- Participate in landscape-level approaches, such as WMAs and conservation programs.
- Build on the strengths of each other.
- Involve community in planting of roadside restoration projects.

In Mississippi, the state DOA provided herbicides for private landowners to treat cogongrass, which successfully raised public awareness and involvement in the political process, including invasive species control. WYDOT's "greatest success has been in partnering with and developing an MOU with the Wyoming Department of Agriculture, Weed & Pest Control section. They are the agency that is statutorily responsible for administering the Wyoming Weed and Pest Act. This allows us to rely heavily on their expertise and relationship with the county weed & pest staffs, thereby reducing redundant efforts on our part." One DOT noted that the "transfer of information between resource groups evolves from the federal government groups down to the local level."

Articles in the summer 2001 *Issues in Science and Technology* (*7*) and a subsequent article in FHWA's *Greener Roadsides* (*119*) discuss the need for a National Center for Biological Invasions to ensure that the United States is better prepared to respond to new invasions and to mange existing. Given the challenges presented by a necessary multijurisdictional response, the authors suggest a model akin to the Centers for Disease Control and Prevention or the National Interagency Fire Center in Boise, Idaho. Both organizations monitor their problem, work on prevention and management, and do so as the problems emerge in a region or nationally. A national center could help increase effectiveness of invasive species control efforts by (*119*):

- Coordinating early detection and rapid response to new invaders among agencies;
- Addressing homeland security concerns;
- Enhancing coordination of prevention and control efforts;
- Increasing information exchange among scientists and technicians;
- Integrating, tracking, and sharing university-based research, and using diverse communications methods for public education about invasions;
- Helping coordinate surveillance and tracking new invasions;
- Assisting existing weed networks and building on existing frameworks and partnerships;
- Ensuring correct species identification; and
- Defining economic impacts and more.

DEPARTMENTS OF TRANSPORTATION LESSONS LEARNED REGARDING INTERNAL COMMUNICATION AND OWNERSHIP

DOTs use internal meetings, internal training, attendance at conferences, communication and networking within and outside the agency, e-mail, phone calls, interdisciplinary working groups, and partnerships with others to share lessons learned within and beyond the DOT regarding invasive species control. Other mechanisms include:

- Annual Vegetation Management Classes/Conference conducted by the DOT, often the Maintenance Bureau (Alabama, Louisiana, Maryland, Minnesota, South Carolina, and Texas).
- Individual Vegetation Management Update Training Session, Sprayer Inspection, and Calibration, pre-season meetings (Maryland and Minnesota).

- DOT Environmental School/Academy (Minnesota) reaches design and construction.
- Periodic Vegetation Management Newsletters sent out from the Maintenance Bureau (Alabama).
- Articles in general/environmental newsletters distributed by the DOT (Arkansas and Texas).
- Changes in specifications (California).
- Networking between District and Central Office, and with other entities and peers (Colorado, Illinois, Indiana, Iowa, Missouri, Nevada, and Texas).
- Pilot efforts/research (Florida).
- Information posted on web board/pages (California and New York).

Mn/DOT developed the following best practices for promoting an IRVM philosophy internally (*120*).

Legislative Considerations

- Communicate to the legislature that IRVM is a worthwhile investment that will result in lower maintenance life-cycle costs. To do so, initial costs must be presented clearly in relation to long-term savings with innovative technologies.
- Maintenance funding must be dedicated at a reasonable base level for accomplishment of all critical maintenance and some preventive maintenance activities.

Upper Management

- Communicate the role that IRVM can play as a problem-solving tool for roadsides.
- Provide the necessary links with design and construction personnel when constructing the roadway.

Maintenance Supervisors

- Recognize that these individuals are the primary resources for motivation, coordination, guidance, training, and follow through on an IRVM program.
- Develop a management system that includes necessary record-keeping and cost-tracking components for measurement and evaluation.
- Require these staff members to develop and implement relevant technology and computer applications for the implementation and practice of the IRVM program.

Maintenance Staff

- Hire, train, and dedicate crews for roadside maintenance.
- Inspire crew members and motivate them to learn and continuously improve the quality of roadsides in their care.
- Recognize those individuals and crews that succeed in improving their roadside environment.

TRAINING APPROACHES

Fourteen DOTs (35% of respondents) provide training for all maintenance forces on invasive species identification, control, and expectations. Some DOTs conduct annual vegetation management classes (Alabama, Arizona, California, North Carolina, Oregon, Pennsylvania, South Carolina, Texas, Utah, and Washington State) or revegetation training for construction inspectors (Texas).

DOA and DNR specialists have also helped conduct training at DOTs and with county roadside maintenance staff. In some states, DOT environmental services sections, landscape architects, and agronomists have conducted invasive species identification and control practices to successfully raise awareness. In some states, resource agencies or the state NHPs have conducted such training. DOT agronomists, landscape architects, and maintenance supervisors have also conducted briefings on DOT invasive species eradication trials and results. Training sessions may utilize handouts, live plants, site visits, powerpoint presentations, and discussion. WSDOT conducts annual training for all state vegetation management personnel; area meetings are held bi-annually to review and refine IVM plans. Attendance at external training workshops and conferences is also an important source of training for DOTs. FDOT sends notifications of external training to all maintenance yards. Herbicide representatives also provide training.

Some of the most effective training is provided on an ongoing basis, taking advantage of as many occasions and forms as possible. In addition to special classes by environmental specialists or landscape architects, district shop meetings, and annual construction and maintenance meetings provide training opportunities. NCDOT conducts on-site tours and presentations during various conferences, in addition to presenting identification materials to division personnel on a regular basis.

DOTs shared ideas and recommendations on what is working best for their agencies that could be used elsewhere.

- Advocate for forming formal partnerships (Arkansas).
- Include project development, design, construction, maintenance, management, and/or planning in invasive species control training courses (Arizona). Get designers involved and aware of their role (Texas).
- Conduct field trips and a weed training school (Colorado). Identification works best when conducted in the field so that personnel can feel and examine the plants (Mississippi). On-site tours are best, as first-hand experience is critical to successful control (Missouri, North Carolina, Pennsylvania, Rhode Island, Utah, and Washington State).
- Become involved with the organizations that put on the annual training, such as the state Vegetation Management Association, and work with them to model the training to best meet the needs of your state and the department (Florida).

- Conduct field training at university research sites (Indiana). Share research with university (North Carolina).
- Promote interest in plants through inclusion of information relevant to home and farm (livestock toxicity, human health concerns, ethnobotany, etc.). For identification, use live plant samples as well as images, including similar looking species in self-corrected quizzes about identification and status; that is, noxious weed, invasive weed, other weed, and wildflower (Iowa).
- Identify targeted weed species and include input from representatives of the chemical industry (Louisiana).
- Conduct annual training sessions at each maintenance shop (Maryland).
- Conduct informal field training sessions entailing "learning by doing." The next best concept is pulling together small informal groups of 20 to 25 maintenance staff (supervisors and front-line workers) for interactive sessions, as is done each spring for "Pesticide Applicator Pre-Season Meetings." An agenda can be followed to ensure consistent messages for key items; however, allow time for informal, constructive, and facilitated dialogue regarding issues and concerns of the local area (Minnesota). Crew-level meetings appear to work the best (Oregon).
- Take the time to work on plant identification. Roadside alerts and/or newsletters help (Missouri and Pennsylvania).
- Provide DOT examples of successful and unsuccessful management techniques (New York).
- Work with your Local Technical Assistance Program (Ohio).
- Educate people in the wide variety of seed transport methods. For example, weed seed may stick to clothing when walking through weed-infested areas.
- Train road maintenance staff and utility truck operators to recognize weeds and report locations to the local weed specialist. Inventory weed infestations and schedule them for treatment.
- Develop weed-awareness programs for local residents, fishing and hunting license holders, the visiting public, and staff members of the different county, state, and federal agencies.

Photographs and control tips for various species are widely available on the web. Furthermore, many resources developed by your state extension service or partner entities may be used in DOT training efforts.

Short training courses relevant to Invasive Species Management include the FWS' Integrated Approach to Invasive Species Management (4 days) at the National Conservation Training Center in Shepherdstown, West Virginia. Courses focused on plants include the following:

- Control Methods for Invasive Plants (one day). New England Wild Flower Society, Framingham, Massachusetts.
- Aquatic Weed Control Short Course (1 week, given annually). University of Florida/Institute of Food and Agricultural Sciences, Office of Conferences and Institutes, Gainesville, Florida.
- Noxious Weed Management Short Course (1 week, given each April), Weed Management Services, Helena, Montana (e-mail: weeds1@ixi.net).
- Short training course on invasive marine species of San Francisco Bay and the central California coast, University of California, Davis, and other institutions.

PUBLIC OUTREACH

Educating range managers, landowners, workers on the land, and the general public about their role in monitoring and controlling the problem increases the success of a vegetation management program. A successful plan to address invasive species issues depends on the public's understanding and acceptance of the actions needed to protect our valuable resources. To that end, a wide variety of education, outreach, and training programs are needed to help motivate people to take action and raise awareness of the causes of establishment and consequences of invasive species. E.O. 13112 directs federal agencies to promote public education and awareness on invasive species, as well as actions to minimize their impacts.

Because many people are unaware that their actions can result in the introduction and spread of invasive species, education and outreach programs constitute an important line of defense for prevention and control. New Hampshire DOT, for example, considers awareness building, literature publication and distribution, and public outreach in general to be their most effective mechanism(s) for combating invasive species.

Mn/DOT developed the following best practices for promoting an IRVM philosophy and associated public involvement (*120*):

- Educate the public on why and how roadsides are managed, including the reasons for roadside vegetation management in relation to functional roadway objectives, surrounding land use, the overall ecosystem, natural processes, and applied technologies.
- Communicate an appreciation for the beauty of self-sustaining, low-maintenance roadsides.
- Communicate the cost savings realized through lower life-cycle maintenance costs, less negative environmental impact, and efficient use of tax dollars.

Bounty programs in Montana successfully involved the community in a cost-effective monitoring and early treatment program for newly invading spotted knapweed (*121*). This bounty program encouraged monitoring by providing a $5 reward for every unmapped infestation and $50 if the

"bounty hunter" could persuade the landowner to control knapweed infestations. During its first year, Stillwater County reported a $4,500 savings in the county weed budget. These bounty programs were successful in finding and treating newly invading weeds; however, for widespread weeds the program was modified by educating local high school students to help with weed control efforts.

In Columbus, Montana, high school students have been involved in weed control efforts since 1990. Students map weed infestations using aerial photographs, study and monitor biocontrol insects and pathogens, and work on DNA testing and biotechnology. This investment in the education of young people results in greater public awareness, which contributes to a concerted effort against weeds (*122*).

With regard to external communication and information exchange, DOTs recommended the following as part of this survey effort:

- Information exchange with various volunteer weed management groups (Arizona).
- Regional and national meetings, such as Roadside Vegetation Managers Association and regional invasive species control meetings (California, Connecticut, New Mexico, North Carolina, South Carolina, and Texas).
- Systems to share species location and control methods with counties and others (Iowa).
- Local Technical Assistance Program (Ohio).

EDUCATIONAL RESOURCES, INFORMATION SOURCES, AND DATABASES

Educational resources are available on-line at www.invasivespecies.org and include:

- Invasive species educational resources, hosted by the National Science Foundation, Center for Integrated Pest Management.
- Conference proceedings, conferences, and workshops.
- A large number of frequently asked questions on general topics, and a wide variety of aquatic species, plants, animals, and microbes. The gateway to federal and state invasive species programs and activities also maintains a library of publications, including CD-ROM products, educational resources for K-12 students, general publications and reports, government and organization fact sheets, newsletters, bibliographies, books and monographs, and scientific journal articles.

Bibliographies by state or other geographic region are also available, as well as a wide range of invasive species databases. FHWA and other organizations have compiled on-line resources for the control of invasive species (*9*).

Resources from The Nature Conservancy include, but are not limited to:

- Element Stewardship Abstracts, which summarize the existing literature on a given plant and provide detailed information on life history, control methods, and research needs.
- Wildland Invasive Species Program and its *Weed Control Methods Handbook*. This handbook reviews manual, grazing, fire, biocontrol, and herbicide techniques.
- The Wildland Invasive Species Program offers decision makers years of land management experience regarding problem plants, control methods, an adaptable power point presentation, a press release template, and ways to utilize volunteers.
- Invasives on the Web includes an interactive map showing invasive plants specific to different regions, a large library of information on controlling invasive plants in your garden, and an extensive photo gallery of invasive species.
- ConserveOnline is a "one-stop" online, public library, created and maintained in partnership with other conservation organizations.

Resources from regional councils and information sites include:

- The Aquatic Plant Information System (APIS)—provides the identification and management of more than 60 species of native and introduced aquatic and wetland plants.
- Center for Aquatic and Invasive Plants—a site that contains images and information for 383 native and nonnative species found in Florida.
- The Prairie Region website—targets invasives. It includes the Heibert ranking assessment.
- Southwest Exotic Plant Information Clearinghouse.
- Center for Invasive Plant Management—home to an in-depth western weed clearinghouse of information.
- Minnesota DNR invasive species pages—includes information on purple loosestrife, other invasive species, and their harmful exotic species program.
- Plant Conservation Alliance Alien Plant Working Group (APWG) (formerly NPCI) Weeds Gone Wild website—a public education project of the APWG focused on invasive plants and their harmful effects on natural ecosystems in the United States.
- USDA, Natural Resources Conservation Service Plants Database—provides extensive database of plant information, as well as numerous links to other useful sites.
- The Roadside Research Project—cooperative project by PennDOT and Penn State University: includes research reports, a discussion forum, publications, and useful links.
- Penn State University Weed Management research and education projects information.
- Mid-Atlantic, California, Florida, and Southeast Exotic Pest Plant Councils.
- Invasive Plants Atlas of New England (IPANE)—searchable database of invasive plants of New England.

- New England Plant Society—comprehensive list of books and links for the Northeast gardener.
- Virginia Native Plant Society—fact sheets on invasive plants.
- Sea Grant Non-Indigenous Species—concerned with aquatic nuisance species.
- Chesapeake Bay Program invasives information—fact sheets and updates on the working group.
- The Bugwood Work Group (managed by the University of Georgia)—resources and tools to enhance and complement information exchange and educational activities primarily in the fields of entomology, forestry, forest health, and natural resources.
- University of Florida, Center for Aquatic and Invasive Plants—plant information and images and bibliographic database on plants.
- Delaware River Basin Commission [Delaware River Invasive Plant Partnership (DRIPP) partner]—information on the Delaware River watershed.
- Pennsylvania Department of Environmental Protection (DEP) (DRIPP partner)—information about the Pennsylvania DEP watersheds protection program and volunteer monitors network.
- Archive of photographs of invasives, a joint project of The Bugwood Network, USDA Forest Service, USDA APHIS Plant Protection Quarantine, and the University of Georgia.
- St. Louis Invasive Plant Species Workshop on Linking Ecology and Horticulture to Prevent Plant Invasions—news on groups working together to prevent new invasions.
- Native Plants Network and Native Plants Journal—information on the propagation of native plants for restoration.
- University of Montana, INVADERS database—exotic plant names and weed distribution records for five northwestern states. The INVADERS website contains actual examples of how land management and weed regulatory agencies are using these data to improve their weed management programs. Noxious weed listings are provided for all U.S. states and six southern tier Canadian provinces.
- The New England Invasive Plant Group—a new organization that networks agencies, organizations, and individuals involved in invasive plant issues in the region. It promotes the sharing of information among network members, research into plant biology and management techniques, alternatives to invasive species still in use, and provides a clearinghouse and referral system for information.
- The New England Wildflower Society—the oldest plant conservation organization in the United States, promoting the conservation of temperate North American plants through programs in conservation, education, research, and horticulture.
- The Invasive Plant Control Initiative Strategic Plan for the Connecticut River Watershed and Long Island Sound Region—highlights agencies and organizations already working on the issue in the watershed and New England, what needs exist, and what actions would best serve the region within 5 years.
- The Connecticut Invasive Plant Working Group—maintains a website on invasive plants and their control, as well as announcements of conferences and other events.
- Invasive Plant Council of New York—website with information on invasive plant species, their control, and their alternatives, as well as a database of resource people experienced with managing them.
- A Guide to Invasive Non-native Aquatic Plants in Massachusetts.
- Wisconsin Manual of Control Recommendations for Ecologically Invasive Plants.
- Native Alternatives for Invasive Ornamental Plant Species—highlights alternatives to four species considered widespread and invasive in Connecticut [autumn olive (*Elaeagnus umbellate*), Japanese barberry (*Berberis thunbergii*), purple loosestrife (*Lythrum salicaria*), and burning bush (*Kochia scoparia*)], and one potentially invasive species in Connecticut [Norway maple (*Acer platanoides*)].

The following works contain useful bibliographies and are included by geographical location:

- *An Illustrated Guide to Arizona Weeds* (*123*).
- *Annotated Literature Review: Model Rapid Response Plan for Great Lakes Aquatic Invasions* (*124*).
- *Control of Invasive Exotic Plants in the Great Plains—An Annotated Bibliography* (*125*).
- *Bibliography of Nonnative Aquatic Species in the Gulf of Mexico and South Atlantic Regions* (*126*).
- *Annotated Bibliography of the Invasive Species of the Gulf Coast—Galveston Bay Invasive Species Risk Assessment Project* (*127*).
- *An Assessment of Exotic Plant Species of Rocky Mountain National Park: Useful References* (*128*).
- *Invasive Pest Plants in the Southern Appalachian Mountain Region Bibliography Database* (*129*).

CHAPTER SIX

CONCLUSIONS

Efforts at invasive species control remain challenged by highly fragmented control efforts among multiple jurisdictions and agencies, usually with inadequate funding or personnel dedicated to such purpose. Although invasive species travel by means of watersheds, vehicles, and by air, irrespective of state borders, coordination of invasive species control efforts across state lines is uncommon.

Inadequate funding is the primary obstacle faced by departments of transportation (DOTs). Most state DOTs consider widespread invasive species inventories and early detection and rapid response efforts to be beyond their means. Only 25% of responding DOTs have undertaken statewide roadside inventories for invasive species to assess what needs and challenges there are and the effectiveness of treatments over broader periods of time and space; another one-quarter of DOTs say they are unlikely to attempt such inventories. Many other DOTs are tackling smaller areas and working to train a wider range of DOT employees and contractors to identify invasive and noxious species and proper responses. One-quarter of the responding DOTs reported that they were impeded by the lack of templates or guidance on invasive species management.

Executive Order (E.O.) 13112 has helped increase DOT awareness of and efforts to control invasive species. A number of DOTs have begun doing species surveys on construction projects, controlling infestations, and revegetating with native species, with lower maintenance requirements. Consideration of long-term maintainability and reduced costs during project development has been a key step in reducing the environmental and economic costs, as well as the overwhelming challenges to DOT maintenance.

Teamwork and training for designing better, more easily maintainable roadsides is also key. Coordination among environmental, design and landscape architectural, and construction staff is increasing, addressing environmental impacts and eradication and control of invasive species before, during, and after construction. DOTs are taking a variety of steps to share information across division areas and professional specialties to address cross-cutting needs and to take a more integrated approach to invasive species control. Information is often exchanged informally; however, chief among the more formal communication approaches are organization-wide and district-specific integrated vegetation management plans. In addition to the growth of integrated planning, geographic information systems now enable the locations of weed patches to be stored digitally, and allow treatments to be tracked and assessed over time. Other technological advances, such as innovative sprayers that can handle multiple herbicides and target individual invasive species, have allowed DOTs to simultaneously reduce herbicides, invasives, and labor costs.

Highly effective, lower-tech communication mechanisms such as posters and laminated illustrations of various top priority weeds are common as well. DOT landscape architects and roadside managers are developing session topics at statewide annual environmental, construction, and maintenance meetings. Training and awareness building, both for DOT employees and contractors, have been essential steps toward effective control of invasives, where this has occurred.

GAPS IN AND OPPORTUNITIES FOR GREATER EFFECTIVENESS IN INVASIVE SPECIES CONTROL

When asked what could facilitate more timely and effective (and simply greater) investment of resources to address the challenge of invasives, many DOTs cited a formalized plan, more funds, and dedicated personnel. Other needs identified are described here.

DOT maintenance managers noted that neglecting the problem(s) presented by invasive species will lead to long-term environmental consequences and higher maintenance costs, and that failing to give high priority to invasive species control could be considered short-sighted. DOTs recommended the following, which are shared here to facilitate greater interagency communication and to leverage the progress that individual transportation agencies are making on areas of potential interest to others:

- A cost–benefit study that couples the problem to personal and public consequences, including the harmful effects of invasives on the roadside environment.
- Better communication in data collection of species, more public education, legislative commitment and support, and funding.
- Upper management support and buy-in, policy, and greater priority in resource allocation.
- A state executive order similar to the federal E.O. 13112. A state weed board to work with counties to

ensure that weed laws are enforced. Invasive species control to be defined and enforced in a way that accommodates slower controls, such as biological control with insects or disease, and plant competition. Research on species origin and natural predators.

DOTs also recommended greater financial resources and requirements that would effectively deliver greater financial resources.

- Additional resources and personnel focused on invasive species, rather than funding through a small portion of routine roadside management or project delivery.
- Dedicated funding of control efforts in maintenance and dedicated funding for roadside restoration and plant establishment in project development.
- Funding resources for inventory.
- More federal funding focused on landscaping, maintenance, and invasive species control and planning.
- Dedicated funds for informational materials such as posters, brochures, and laminated invasive species cards for the field.
- If DOTs can get 3 years of federal funding for landscape establishment under federally funded construction projects, they should be able to get 3 years for turf establishment to help address the higher maintenance costs of establishing native species.
- Legal requirements for restoration of disturbed areas.

Inventory, tracking, planning, management, and reevaluation—versions of PLAN-DO-CHECK-ACT—were identified as key opportunity areas in advancing invasive species control. In particular, DOTs mentioned the following:

- Strategic planning, statewide management plans, and datasets.
- Species inventory, prioritization, and treatment planning and timing.
- Activity numbers to increase ways of tracking methods, successful control of invasives, and costs.
- Addition of a Roadsides Division within the DOT.
- Attention to construction-related issues, including aggregate sources, topsoil management, and methods to relieve construction soil compaction.
- Development and use of replicable methodologies for assessing success.

DOT respondents provided the following comments on control methods:

- Improved control techniques, especially biological controls.
- More research on cultural controls.
- Control and focus; that is, do it once, do it right, and move on.
- Cooperation and cross-functional areas. Total involvement.

Examples of interagency and external coordination were supplied by several DOTs:

- All of the state's departments (Transportation, Agriculture, Forestry, Wildlife, and Fisheries) dealing with invasive species should gather their resources to identify the problems and address them in conjunction with each other.
- Statewide Invasive Species Council, advisory group, and regional work groups.
- Prompt control of new outbreaks on private property.
- National focus.

DOT invasive species control staff also described areas in which their agency is in need of successful examples from others. This report addresses these issues and fills some of these gaps; however, this list is presented here in full to facilitate assistance between DOTs.

- Examples in which a small staff has initiated and generated statewide agency support for a control campaign for a specific invasive problem (Alabama).
- Examples of statewide invasive inventories and control strategies that have saved dollars and protected natural resources (Minnesota).
- Examples of cost savings, pavement preservation, or low-cost native plantings that resulted from controlling invasive species or implementing a department-wide invasive species control plan (Pennsylvania).
- Examples of how the invasive species programs can be effectively brought into the routine roadside management, yet quantified separately (California and Florida).
- Single treatment of invasive species by species, timing, and method and application rate could be very beneficial (California).
- Illustrations of upper departmental commitment and involvement (Arizona).
- Overcoming public aversion to the use of herbicides required as part of an Integrated Vegetation Management plan (Arkansas).
- Roadside species inventories and funding (Virginia).
- Better communications between agency divisions on what is being done and what could be done to help in control of invasive plants, insects, and animals (Florida).
- Program management with limited resources (New Mexico).
- Funded plans to manage invasive species (Indiana).
- Practical, efficient, and cost-effective control methods given limited funds (Illinois, New York, and Ohio).
- Callery pear (*Pyrus calleryana*) control (Arkansas).
- Selective grazing weed control examples (Wyoming).
- Examples of cost-effective and small-budget partnerships to successfully combat invasives (Connecticut).

- Acquiring funding and resources to address these problems (Louisiana).
- Examples of revegetation with natives in arid environments (Nevada).
- Before and after photographs (New Hampshire).
- Attention and involvement from design and construction departments (Texas).

ESTIMATING BENEFITS OF INVASIVE SPECIES CONTROL

To date, the benefits of invasive species control have been little quantified by DOTs. Roadside managers are well aware of the costs of ignoring invasives and the greater herbicide and mowing expenses that can be incurred, but express a particular need for examples where statewide invasive inventories and control strategies have saved money and protected natural resources. Most of the evidence is anecdotal. Invasive species such as kudzu can obliterate stop signs with safety consequences. DOTs cited reduced maintenance and mowing cycles with reductions of invasive species, and provided the following examples of streamlining and cost reductions from invasive species control:

- In Arizona, the I-40 Camelthorn (*Alhagi maurorum*) control project assisted Arizona DOT maintenance in the preservation of highway integrity, at a cost savings exceeding $1 million per lane-mile.
- Costs of not treating invasives have been verified in Florida. The two species Florida DOT maintenance identifies and monitors were treated to the right-of-way limits, only to have it spread back to the right-of-way from adjacent untreated property.
- Cost savings from treatment has been verified in Iowa. Controlling a small, isolated infestation of spotted knapweed (*Centaurea biebersteinii*) on the right-of-way resulted in containing its spread throughout the area. This resulted in cost savings insofar as additional areas did not need to be treated.
- In Louisiana, the reduction of itchgrass (*Rottboellia cochinchinensis*) in southwestern Louisiana has reduced the annual mowing frequency.
- New Hampshire is in the process of calculating data in this area.
- With New York State DOT, invasive species control activities led directly to the development and issuance of a General Permit by the Adirondack Park Agency for certain control practices that previously required an individual permit with lengthy reviews and public comment periods.
- In Wyoming, the long-term commitment of Wyoming DOT divisions and County Weed partners to a true integrated weed management system has resulted in the lowest herbicide expenditures by any DOT in the nation (i.e., less than $1 million in herbicide expenditure annually on a 7,000 mi system).

DOTs shared a number of ideas and suggestions for achieving better estimates of the benefits of invasive species control:

- By the acre and in terms of reduction of maintenance costs, need for mowing, and erosion and sedimentation control treatments and less herbicide use over time.
- By sampling and monitoring specific sites tracking species treated, including size and density, treatment, and habitat (other species present). Evaluate data collected annually to determine if there is a reduction or elimination of the invasive species and if there is a change in the habitat composition as a result of treatment.
- Track the total cost of the actual control effort, including inventory, training, materials, equipment, person-hours and monitoring of effectiveness and subsequent control costs. This will help determine what the controls cost in relation to environmental and societal benefits provided.
- Estimate damages and costs to mitigate or restore native vegetation. Estimate loss of previous and potential value of land infested with invasive species based on the extent of infestation and how that affects land use or cost to recover. Estimates could include potential for spread, rate of spread, and potential loss of value of land estimated to be affected.
- Quantify the dollar value from losses in tourism and agriculture.
- Quantify the benefits of biodiversity, species richness, and suitable habitat and for people, fewer environmental contaminants and better service to and public relations with adjacent property owners.
- Tracking public complaints; the absence of weed control becomes evident very quickly.
- Track compliance with sister agencies' goals.

Although the lack of metrics has made it difficult for DOT maintenance managers to make the case for significant increases in investment in invasive species management, asset management principles and documentation of life-cycle costs incurred by the failure to prevent the spread of invasive species through DOT actions throughout the project development, construction, and maintenance process can begin to fill this gap.

FURTHER NEEDS AND RESEARCH AREAS

DOTs were clear that funding is a primary need and that a stronger federal role in this area would be helpful. SAFETEA-LU offers no additional funding, although invasive species control is increasingly eligible for support through existing funds allocations. SAFETEA-LU does require DOTs to coordinate with state and local government conservation plans.

Additional research needs suggested included:

- DOT methods and experience in evaluating and enforcing the use of invasive species prevention practices during construction, including:
  - Effective use of existing contract provisions.
  - Impact of low-bid methods on priorities incidental to roadway construction such as invasive species control and inspection.
- Specific guidelines, policies, and templates for Integrated Roadside Vegetation Management planning and challenges such as poor soil, compacted soils, and disturbed and degraded roadsides.
- DOT methods and systems for tracking system for segments of right-of-way that come under federal funding for purposes of compliance with E.O. 13112 at any given time and that also facilitate tracking of the revegetation process and status and effective hand-off of maintenance responsibilities.
- Identification of methods and best practices in design and performance of roadside inventories, including modification of existing enterprise geographic information and maintenance management systems.
- Strategic planning, budgeting, and timing treatment and equipment. Examples are needed of how the invasive species programs can be effectively brought into routine roadside management, yet quantified separately.
- Cultural and biological control methods for invasive species.
- Models for communication and building awareness, support, and involvement within the agency and among partners.
- Development of fast and practical ways to exchange efficient and cost-effective control and revegetation methods given limited funds.

DOTs are still documenting and proving the business case for investing in greater invasive species control. Therefore, better cost–benefit information, to demonstrate that the value and urgency of timely response to infestations is a primary need as well, is discussed in greater detail in the following section.

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GLOSSARY

Adaptive management—rigorous application of management, research, and monitoring to gain information and experience necessary to assess and modify management activities. A process that uses feedback from research, monitoring, and evaluation of management actions to support or modify objectives and strategies at all planning levels.

Alien species—with respect to a particular ecosystem, any species, including its seeds, eggs, spores, or other biological material, capable of propagating that species that is not native to that ecosystem.

Biological control—direct and purposeful manipulation of natural enemies, pest competitors, or the resources required by these organisms for the reduction of negative economic, ecological, or aesthetic impact cause by weeds or other pests.

Boise–Vale system—Idaho/Oregon Bureau of Land Management Weed Database.

Clean Water Act Nonpoint Discharge Elimination System (NPDES)—permit program that controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete conveyances such as pipes or man-made ditches.

Control—as appropriate, eradicating, suppressing, reducing, or managing invasive species including restoration of native species and habitats to reduce the effects of invasive species and to prevent further invasion.

Cover type—present vegetation of an area.

Cultural control—cultural weed management largely involving manipulating practices to suppress weed growth and production, while promoting the development of desired plants. Common practices include preventing the spread of weeds between sites, encouraging the competitiveness of desired species, and using mulches and cover crops.

Dedicated funding, dedicated personnel—funding specifically earmarked or directed to a specific purpose.

Early Detection and Rapid Response (EDRR)—system to detect, report, identify, and immediate attempts to eradicate or control suspected new invasive plants with free living populations in the United States.

Ecological integrity—ecosystems have integrity when deemed characteristic for its natural region, including the composition and abundance of native species and biological communities, rates of change, and supporting processes. In plain language, ecosystems have integrity when they retain their native components and complexity (plants, animals, and other organisms) and processes (such as growth, reproduction, energy flow, and nutrient cycling) to maintain the ecosystem's capacity for self-organization through time.

Ecosystem—dynamic and interrelating complex of plant and animal communities and their associated nonliving environment.

Ecosystem management—management of natural resources using system-wide concepts to ensure that all plants and animals in ecosystems are maintained at viable levels in native habitats and basic ecosystem processes are perpetuated indefinitely.

Ecotype—smallest taxonomic subdivision of species, consisting of populations adapted to a particular set of environmental conditions.

Endangered species (federal)—plant or animal species listed under the Endangered Species Act that is in danger of extinction throughout all or a significant portion of its range.

Endangered species (state)—plant or animal species in danger of becoming extinct or extirpated in an individual state within the near future if factors contributing to its decline continue. Populations of these species are at critically low levels or their habitats have been degraded or depleted to a significant degree.

Environmental assessment (EA)—concise public document, prepared in compliance with the National Environmental Policy Act, that briefly discusses the purpose and need for an action, alternatives to such action, and provides sufficient evidence and analysis of impacts to determine whether to prepare an Environmental Impact Statement or Finding of No Significant Impact (40 CFR 1508.9).

Environmental Impact Statement (EIS)—detailed written statement required by section 102(2)(C) of the National Environmental Policy Act, analyzing the environmental impacts of a proposed action, adverse effects of the project that cannot be avoided, alternative courses of action, short-term uses of the environment versus the maintenance and enhancement of long-term productivity, and any irreversible and irretrievable commitment of resources (40 CFR 1508.1 I).

Environmental Management System (EMS)—identification of aspects of operations that may impact the environment; also a step in the development of a system to manage environmental impacts.

Fauna—all vertebrate and invertebrate animals of an area.

Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW)—formal partnership between 16 federal agencies with direct invasive plant management and regulatory responsibilities spanning the United States and its territories. FICMNEW was established through a Memorandum of Understanding in August 1994.

Finding of No Significant Impact (FONSI)—document prepared in compliance with the National Environmental Policy Act, supported by an Environmental Assessment, that briefly presents why a federal action will have no significant effect on the human environment and for which an Environmental Impact Statement, therefore, will not be prepared (40 CFR 1508.13).

Flora—all the plant species of an area.

Forb—broad-leaved, herbaceous plant.

Geographic information system (GIS)—computer system capable of storing and manipulating spatial data.

Global Positioning System (GPS)—worldwide radio navigation system, formed from a constellation of 24 satellites and their ground stations, used to calculate positions accurately.

Goal—descriptive, open-ended, and often broad statements of desired future conditions that convey a purpose but do not define measurable units.

Habitat—unique characteristics of abiotic and biotic environments; a place where an organism typically lives.

Habitat type—see vegetation type.

Incident Command System (ICS)—standardized, on-scene, all-hazard incident management concept. ICS allows its users to adopt an integrated organizational structure to match the complexities and demands of single or multiple incidents without being hindered by jurisdictional boundaries.

Indicator species—species of plant or animal that is assumed to be associated with certain habitat or environmental conditions (pristine or deteriorated).

Integrated pest management—methods of managing undesirable species (such as weeds) including education, prevention, physical or mechanical methods of control, biological control, responsible chemical use, and cultural methods.

Integrated Roadside Vegetation Management (IRVM)—Integrated Vegetation Management as applied to roadsides or the highway right-of-way.

Integrated Vegetation Management (IVM)—Integrated Pest Management as it applies to vegetation.

Invasive species—alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.

Issue—any unsettled matter that requires a management decision; for example, an initiative, opportunity, resource management problem, threat to the resources of the unit, conflict in uses, public concern, or the presence of an undesirable resource condition.

Monitoring—process of collecting information to track changes of selected parameters over time.

National Cooperative Highway Research Program (NCHRP)—administered by TRB and sponsored by the member departments (i.e., individual state departments of transportation) of AASHTO, in cooperation with FHWA. NCHRP was created in 1962 as a means to conduct research in acute problem areas that affect highway planning, design, construction, operation, and maintenance nationwide.

National Environmental Policy Act of 1969 (NEPA)—requires all agencies, including the U.S. Fish and Wildlife Service, to examine the environmental impacts of their actions, incorporate environmental information, and use public participation in the planning and implementation of all actions. Federal agencies must integrate NEPA with other planning requirements, and prepare appropriate NEPA documents to facilitate better environmental decision making (from 40 CFR 1500).

National Invasive Species Council (NISC)—interdepartmental council that helps to coordinate and ensure complementary, cost-efficient, and effective federal activities regarding invasive species. The Council was established February 3, 1999, by Executive Order 13112.

National Wildlife Refuge System—various categories of areas including all lands, waters, and interests therein administered by the Secretary as wildlife refuges, areas for the protection and conservation of fish and wildlife that are threatened with extinction, wildlife ranges, games ranges, wildlife management areas, or waterfowl production areas.

Native species—a species that historically occurred in a particular ecosystem.

Natural—pertains to the ecosystem components (biological, physical, and chemical) and processes (geological, hydrological, and biological) before the influence of western man.

Notice of Availability (NOA)—notice that documentation is available to the public on a federal action, published in the *Federal Register*.

Notice of Intent (NOI)—in the case of a federal action, such as analyzed in this documentation, an NOI is a notice that an environmental impact statement will be prepared and considered (40 CFR 1508.22); published in the *Federal Register*.

Noxious weed—plant species designated by federal or state law as generally possessing one or more of the following characteristics: aggressive or difficult to manage; parasitic; a carrier or host of serious insect or disease; or nonnative, new, or not common to the United States. According to the Federal Noxious Weed Act (PL 93-639), a noxious weed is one that causes disease or had adverse effects on man or his environment and, therefore, is detrimental to the agriculture and commerce of the United States and to the public health.

Objective—concise target statement of what will be achieved, how much will be achieved, when and where it will be achieved, and who is responsible for the work. Objectives are derived from goals and provide the basis for determining management strategies. Objectives should be attainable and time-specific and should be stated quantitatively to the extent possible. If objectives cannot be stated quantitatively, they may be stated qualitatively (Draft Service Manual 602 FW 1.5).

Plant Association—classification of plant communities based on the similarity in dominants of all layers of vascular species in a climax community.

Plant Community—assemblage of plant species; a reflection or integration of the environmental influences on the site such as soil, temperature, elevation, solar radiation, slope, aspect, and rainfall.

Plant Protection Act (PPA)—law that consolidates all or part of 10 existing U.S. Department of Agriculture plant health laws into one comprehensive law, including the authority to regulate plants, plant products, certain biological control organisms, noxious weeds, and plant pests. The Plant

Quarantine Act, the Federal Pest Act, and the Federal Noxious Weed Act are among the 10 statutes the act replaces.

Prescribed fire—skillful application of fire to natural fuels under conditions of weather, fuel moisture, soil moisture, etc., that allow confinement of the fire to a predetermined area and produces the intensity of heat and rate of spread to accomplish planned benefits to one or more objectives of forest management, wildlife management, or hazard reduction.

Rhizome—underground (usually), horizontal stem of a plant that often sends out roots and shoots from its nodes.

Right-of-way (ROW)—authorization to use a specific piece of public land for a certain project such as roads, pipelines, transmission lines, and communication sites, granted by Bureau of Land Management.

Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)—August 10, 2005, legislation that authorizes the federal surface transportation programs for highways, highway safety, and transit for the 5-year period, 2005–2009.

Serpentine soil—dry, nutrient-poor soil containing the mineral serpentinite. Soil has a greenish color from fragments of the underlying bedrock containing magnesium silicate. Serpentine soils often have pockets of naturally occurring heavy metals toxic to plants such as chromium, cobalt, and nickel.

Succession—process of change and development in community components; soil, microorganisms, animal and plant life, and microenvironment.

Threatened species (federal)—species listed under the Endangered Species Act that is likely to become endangered within the foreseeable future throughout all or a significant portion of their range.

Threatened species (state)—plant or animal species likely to become endangered in an individual state within the near future if factors contributing to population decline or habitat degradation or loss continue.

Vegetation type, habitat type, forest cover type—land classification system based on the concept of distinct plant associations.

Weed Information Management System (WIMS)—Microsoft Access-based relational database application designed to assist natural resource managers in managing their weed data. WIMS keeps track of three types of data records: weed occurrences (GPS point locations), assessments (size and status of the weed infestation to facilitate monitoring over time), and management treatments applied to those weed infestations. Data can be easily exchanged between multiple users, exported in NAWMA (North American Weed Management Association) standards, and written to shapefiles for mapping in any standard GIS program.

APPENDIX A

Survey Questionnaire

NCHRP Synthesis 36-05
Control of Invasive Species

DIRECTIONS: TEXT ANSWER BOXES HAVE UNLIMITED SPACE WITH BOXES, PLEASE CHECK ALL THAT APPLY

Priorities, Drivers, and Obstacles in Your DOT's Approach to Invasive Species Control

1. **Top priorities.** What are your agency's top five invasive species priorities?

   _____

   _____

   _____

   _____

   _____

   Does your agency control or eradicate invasive species that are not plants/weeds (e.g., gypsy moth, West Nile Virus, zebra mussel, fire ants, oak wilt, etc.). If so, please list:

   _____

2. **Drivers.** What are the drivers for your agency in addressing invasive species?

   ☐ Public input, surveys, customer complaints

   ☐ Internal DOT policies, interests, or commitments

   - ☐ Environmental stewardship/vegetative diversity
   - ☐ Maintenance cost savings/containment
   - ☐ Minimizing health or safety hazards
   - ☐ Other. Please describe: _____

   ☐ Executive Order 13112 and FHWA implementing guidance

   ☐ Other agency policies or requests. Please identify: _____

3. **E.O. 13112.** How has the 1999 E.O. 13112, described in the cover letter to this questionnaire, changed how your organization does business?

   ☐ No ☐ Yes, in this manner: _____

   - Added work in planning and/or project development? ☐ No ☐ Yes

   Please describe: _____

   - Additional work in project development? ☐ No ☐ Yes

   If yes, do you have

   - Incorporation of invasive species assessments in all NEPA evaluations?

     ☐ No ☐ Yes

   - Invasive species assessments only in EAs? EISs? ☐ No ☐ Yes
   - Other: _____

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Obstacles/Challenges. What are the main obstacles you have encountered in implementing E.O. 13112 and greater invasive species control?

- ☐ Lack of templates or guidance on invasive species management
- ☐ DOT control limited to ROW and ongoing invasions from adjacent private land
- ☐ Lack of state funds for maintenance of existing ROW
- ☐ Limited availability of federal highway funds for maintenance of existing roadsides
- ☐ Finding suitable native groundcovers to compliment existing seed mixes
- ☐ Perception of native grasses as being difficult or slow to establish
- ☐ Supply of native seed
- ☐ Lack of independent certification of weed-free mulch
- ☐ Differing priorities of federal, state, and local agencies

Other: _____

Key Concepts

4. **Prevention and Management Practices.** Please check any of the following prevention measures or management practices your agency undertakes.
   - ☐ Vegetation Management Plan in each district addressing major issues
   - ☐ Mapping/monitoring/tracking location and treatment of key invasive species
   - ☐ Imported soils must be weed free
   - ☐ Stockpiling of uncontaminated topsoil
   - ☐ Seed mixes must be weed free
   - ☐ Broadleaf herbicide application over turf grass
   - ☐ State/contract mowers required to clean equipment
   - ☐ Mowing heavy infestations last
   - ☐ Design/specification measures for low maintenance/native species
   - ☐ Desired best practices built into staff procedures and specifications for contract work
   - ☐ Systematic pretreatment of weeds/invasives on construction sites
   - ☐ Training of contractors and field personnel
   - ☐ Ongoing research of invasive control and native reestablishment strategies

   Contact: _____

   Other: _____

5. **Reliance on Native Grasses and Forbs.** Does your agency rely on native grasses and forbs in erosion control, landscaping, and revegetation? ☐ No ☐ Yes. Comment: _____

   _____

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If yes, then **what primary actions does your agency take to implement or ensure this**?

- ☐ Vegetation and revegetation according to statewide or regional vegetation plan
- ☐ Required seed mixes have been designed for a variety of ecoregions, slope aspects, etc.
- ☐ DOT policies or agency-wide design specifications
- ☐ Special provisions in contracts for particular projects
- ☐ Landscape architect comments on landscape plans during reviews

Other: _____

Whether yes or no, **what have been your primary obstacles in greater use of native species**?

- ☐ Availability of plant material or desired seed mixes
- ☐ Cost of desired materials and/or available agency funding
- ☐ Public's desire for ornamentals or other non-natives considered more aesthetically pleasing
- ☐ Length of time to establish and/or short growing season
- ☐ Acceptance/education internally or among contractors
- ☐ Contracting process and lack of control over contractors' schedules
- ☐ Limited research regarding what works, especially _____
- ☐ Other agency requirements: _____
- ☐ Other: _____

Does your agency have a **policy or plan for planting/reestablishing native species**?

- ☐ No
- ☐ Plans on some projects/corridors only
- ☐ Statewide plan/policy is being developed

Contact name/e-mail for statewide plan/policy: _____

☐ Yes, a policy and/or plan is already in place. **Is the policy or plan working**?

☐ No ☐ Yes

Why or why not? _____

Please attach a copy of your agency's policy or plan.

Are **seed mixes** designed and specified for each project?

☐ No ☐ Not yet, but this is in the works

Yes ☐ All ☐ Most

- ☐ Menus of seed mixes have been developed for each ecoregion
- ☐ Seed mixes are modified for project microclimates

Other comment: _____

What would further assist your DOT in this area? _____

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Do you feel your DOT has **adequate ecological or botanical expertise** to provide sufficient help for design, construction, and maintenance in this area? ☐ No ☐ Yes

Who needs more support? _____
What is needed to help them, in your opinion? _____

What are the state's **native seed sources**? (Please check all that apply.)

☐ None available/known

☐ None available locally/in-state

☐ Sources insufficient to meet demand

☐ Several sources available, adequate supply

☐ Seed collection program or seed bank in place

☐ Certification required for native seeds/sources

☐ Other: _____

To what extent have you **protected native plant community remnants on rights-of-way**?

☐ All projects are screened for the presence of rare plant communities in the work zone/ROW

☐ Native/rare plant communities are identified in EAs and EISs

☐ Areas in need of special management are identified by resource agencies or state Natural Heritage Program

☐ Special management areas are identified by DOT staff and managed accordingly by maintenance forces. Please attach information or explain how this is being accomplished

☐ Reduced mowing widths (e.g., one mower width) are standard statewide

☐ A conservation mowing/spraying program has been developed to protect native communities, minimize maintenance costs, and control invasives

☐ DOT has mapped and is tracking protected communities on DOT ROW, statewide.
Primary contact is: _____

Can you/your DOT estimate the total acreage of high-quality forest, wetland, or native grassland remnants you are protecting in the ROW?

☐ No ☐ Yes, approximately: _____

Staffing

6. Who are the three **most active individuals in your agency in efforts to control invasive species**?

Is your DOT interested in further information sharing? ☐ No ☐ Yes

If so, please provide:

Name	Position	Phone/e-mail
_____	_____	_____
_____	_____	_____
_____	_____	_____

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7. Do you have a central person/staff for an **Integrated Roadside Vegetation Management (IRVM) program or invasive species control program**?

   ☐ No ☐ Yes

   Name Position Phone/e-mail

   _____ _____ _____

   Please attach information/documentation on your program with your reply.

8. How has your DOT addressed **staffing needs for invasive species control**?

   ☐ No particular staffing plans have been developed for invasive species control

   ☐ Staffing needs for invasive species control have been addressed as attached or as follows:

   _____

9. What is your **mix of state, contract, city/county, or volunteer forces**?

   ☐ State forces handle all weed control

   ☐ Some weed control is contracted out or otherwise performed by cities and counties

   ☐ Private contract forces are used for some weed control

   ☐ Private forces are used for some/all weed control

   ☐ Partnerships with nonprofit or nongovernmental conservation groups help accomplish some invasive species control in the ROW. ☐ Off ROW as well. Please describe:

   _____

   ☐ Partnerships with private landowners help accomplish invasive species control adjacent to the ROW. Please describe: _____

Organizational Approaches and Division of Effort

10. What **organizational mechanisms or approaches** has your DOT taken to tackle invasive species?

    ☐ None/not applicable

    Awareness, Planning, and Training

    ☐ Policies/procedures have been developed

    ☐ DOT has mapped and is tracking/monitoring areas of infestation

    ☐ Integrated roadside vegetation management plans are in place, statewide or by district

    ☐ Roadside managers in each district manage planning for and awareness of invasives

    ☐ Posters and/or laminated field identification tools are used to raise awareness

    ☐ Training for all maintenance forces on invasive species identification, control, and expectations. Please attach or describe: _____

    ☐ Summer field tour for roadside and maintenance staff to build awareness, share roadside research/field findings, and for districts to compare control programs

    ☐ Newsletters or fact sheets. Please attach.

    ☐ An electronic web space or information sharing group has been established to promote communication, updates on outbreaks, and information exchange/technology transfer

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- ☐ An agency-wide work group has been developed with representation from all regions and functional groups
- ☐ Systems have been developed and implemented for prevention, detection, analysis, control, and management
- ☐ Annual research reports, geared to field. Please attach.

Methods/Practices

- ☐ For all projects and activities, designers and maintenance managers inventory, consider impacts of, and incorporate appropriate management techniques for priority invasive plant and animal species
- ☐ All construction sites are reviewed
- ☐ Contractors are prequalified based on experience and quality of work
- ☐ Dirt and gravel sources are evaluated
- ☐ Construction sites are pretreated before disturbance
- ☐ Policies are in place and enforced to minimize disturbed/opened area (construction phasing). Please attach specs and comment on effectiveness in your state:

  _____

- ☐ Desirable/uncontaminated topsoil is stockpiled to facilitate revegetation
- ☐ Badly infested material is excavated and buried
- ☐ All disturbed areas are restored via application of grass seed and mulch within 2 weeks of disturbance. This may require use of temporary seeding/mulching during the project and additional final restoration at the completion of construction activities in the area.
- ☐ Weed-free mulches are specified on all projects
- ☐ Inert mulch products such as straw or wood fiber are used in sensitive areas
- ☐ Specifications are in place on project plans and bid contracts that seed and sod sources must be free of invasives/weeds
- ☐ Native seed sources are specified and only regional ecotypes are used
- ☐ Native seed mixes use approximately _____ native grass and forbs species per mix:

  _____

- ☐ Contract grown native plants have been used when economically justified
- ☐ Vehicles are washed before and after use
- ☐ Mowing occurs in an order to minimize seed transfer
- ☐ Biological controls (e.g., insects) are used
- ☐ Cultural control methods such as ☐ burning, ☐ restoration, or ☐ grazing are used
- ☐ Roadway shoulders are treated prior to scraping
- ☐ Mowing is timed to control invasive species; i.e., prior to seed maturity
- ☐ Handpicking of invasive species is employed in some areas
- ☐ All ROWs reviewed and treated annually for invasives

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Partnerships

- ☐ DOT has conducted a survey of other agencies/organizations' invasive species work, approaches, or priorities
- ☐ DOT participates in and partners with state noxious weed committee
- ☐ DOT participates in and partners with local Weed Management Areas
- ☐ DOT participates in watershed planning efforts
- ☐ DOT participates in Prevention, Early Detection, and Rapid Response and Inventory Programs. Please attach or describe: _____
- ☐ DOT partners with university to conduct state research
- ☐ DOT works with another agency, _____, to have them review and treat ROW
- ☐ Partnerships with others. Please attach or describe: _____

If you have any **comments on what has been the most successful/effective at your agency**, please tell us here: _____

Are the strategies your agency employs to deal with invasive species problems too limited by your lack of **authority**? ☐ No ☐ Yes

Are the strategies your agency employs to deal with invasive species problems too limited by a lack of **funding**? ☐ No ☐ Yes

11. Please check any of the following **departments that are involved in control of invasives and describe key actions underway**:

- ☐ Management
- ☐ Planning
- ☐ Project development
- ☐ Design
- ☐ Construction
- ☐ Maintenance

Also, please note **what your agency is not doing that you think would make the most difference**.

_____

12. What **aspects of your agency's work or points in the decision-making process(es)** should receive more attention in order to effectively prevent and control invasive species?

_____

13. What is your organization doing to **share information across division areas** and professional specialties, to address cross-cutting needs, or to take a more integrated approach?

_____

14. Please describe any **initiatives/**ongoing efforts by your agency to accomplish the following, on a program level:

- **Link identified locations of invasive species infestation to treatment plans;** track whether and how treatment plans are implemented, monitor the effectiveness of treatment/control, and evaluate progress on a management level.
- **Offer system/staff incentives for effective performance**.
- **Revise treatment plans and reallocate resources** if necessary.
- **Develop systems to document the above and continually improve**.

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15. What is the **funding stream for invasive species control** in your department?

☐ General maintenance funds, no separate budget item for control of invasives

☐ Budget for Integrated Roadside Management or invasives control

Other: _____

Assessment, Inventory, and Tracking

16. Is your DOT formally **identifying aspects of its activities that impact/promote invasive species**?
☐ No ☐ Yes

If so, please attach the**tools/forms/process description** you are using to do so, or end documentation produced by the process. Comment:_____

17. If your DOT has undertaken a **statewide inventory of invasive or noxious species in the ROW**:

- When was that completed? _____
- How is it being updated? _____
- How is it being used to guide and evaluate invasive species control efforts?

  _____
- Was GIS employed? ☐ No ☐ Yes
- Who did the field inventory work? _____
- Have you determined the rate of spread of any one weed? ☐ No ☐ Yes

  What rates have you determined? _____

If your DOT has not completed such a survey:

- Is one in process? ☐ No ☐ Yes; if so, when will that be completed? _____

  Are interim results being used? ☐ No ☐ Yes
- Does the DOT plan to implement one in the future? ☐ No ☐ Yes

  Timeframe: _____

Please attach a description of any ongoing efforts by your agency to locate and track invasive species in the ROW.

Manuals, Innovative Methods, Rapid Response, and Restoration

18. Please describe any practices of your agency with regard to:

- **Rapid response** where populations found. _____
- **Native species planting practices and restoration of invaded habitats**. _____

  _____

19. What **resources, policies, management plans, manuals, or guidelines** does your DOT have to control invasive species? _____

Please provide electronic copies or web locations, if possible.

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20. Please **describe and/or share innovative models of methods, equipment, bids, etc**. With regard to various management practices, please share any innovative methods you have developed or findings you have made (including notable failures for others' learning benefit).

_____

Partnerships and Support

21. **Where do you go for help**?
    - ☐ Universities
    - ☐ Internet
    - ☐ Other agencies
    - ☐ County weed personnel
    - ☐ Nongovernmental and/or conservation organizations
    - ☐ Other DOTs
    - ☐ AASHTO, NCHRP, or FHWA
    - ☐ Chemical company representatives
    - ☐ Other: _____

22. Is your DOT **working with others to identify existing or emerging populations of invasives**?
    ☐ No ☐ Yes

23. Is there an **enforceable invasive species law in your state**? ☐ No ☐ Yes

24. With regard to **Invasive Species Councils and Task Forces**:
    - Has a statewide invasive species task force been formed in your state?
      ☐ No ☐ Yes
    - Is the DOT actively involved? ☐ No ☐ Yes
    - Do you consider the Council or Task Force a success? ☐ No ☐ Yes. Why or why not?
      _____
    - If so, what are its key strengths, successful approaches, or accomplishments that may serve as models to others? _____

25. With what **agencies/NGOs** are you working in your state? _____
    Please identify the ways you are cooperating with each. _____

26. What **successful, efficient strategies can you suggest/share for coordinating** with others?
    _____

27. Is your agency involved in **cooperative efforts across state lines**? ☐ No ☐ Yes

    If so, please identify: _____

28. To what extent does your agency rely on or **partner with weed management districts or weed management areas**, etc? _____

    What are some of the **benefits and limits** of these partnerships? _____

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29. How does your agency consider/incorporate **local weed lists** without getting bogged down?

_____

30. How does your agency deal with **private property issues** and invasives or noxious weed control?
    - ☐ DOT does not treat private property. DOT only works on ROW or where DOT has easements or borrow areas
    - ☐ DOT will make landowner aware of problem and let them know about other resources/programs to assist them
    - ☐ DOT has on occasion obtained landowner permission to control on properties adjacent to the ROW
    - ☐ Lack of up-to-date statewide invasive species inventory information hampers coordination of control efforts with others
    - ☐ Nongovernmental and/or conservation organizations
    - ☐ Other DOTs
    - ☐ AASHTO, NCHRP, or FHWA
    - ☐ Chemical company representatives
    - ☐ Other: _____

31. What **obstacles does your agency face in coordinating with others**? _____

_____

32. **What is needed that would help**? _____

Technology Transfer and Training

33. How is your agency **sharing lessons learned** within and outside the DOT? _____

_____

34. How is your agency **training staff** in invasive species/noxious weed control? _____

_____

35. **What is** working **best for you in training** that could be utilized elsewhere? _____

_____

36. Please attach **a list of the research your agency has underway or has funded in the area of invasive species control**. Please identify types of research, length in years, species targeted, methods explored, and other information you think may be valuable for your peers to know. What are your **top five findings/discoveries** in the past five years?

_____

_____

_____

_____

_____

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Streamlining and Results

37. How would you **quantify the benefits of invasive species control**? _____

38. Do you have **any examples of how invasive species control efforts streamlined other agency processes or saved money/resources**? _____
_____

Last Questions

39. What **missing links** could facilitate more timely and effective (and simply greater) investment of resources to address the challenge of invasives? _____

40. Are you/your agency **in need of successful examples from others in certain areas**? If so, please describe: _____
_____

41. What **unaddressed opportunity areas** do you see for effective control of invasives that should be explored further? _____
_____

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APPENDIX B

Respondents to Survey Questionnaire

Alabama
Alaska
Arizona
Arkansas
California
Colorado
Connecticut
Florida
Hawaii
Illinois
Indiana
Iowa
Kansas
Kentucky
Louisiana
Maryland
Minnesota
Mississippi
Missouri
Montana
Nebraska
Nevada
New Hampshire
New Mexico
New York
North Carolina
Ohio
Oregon
Pennsylvania
Rhode Island
South Carolina
South Dakota
Texas
Utah
Vermont
Virginia
Washington
West Virginia
Wisconsin
Wyoming

U.S. Forest Service

APPENDIX C

Sample New York State Department of Transportation Invasive Species Inventory Forms

NYSDOT Database (Reference #): _____ **DOT (Road/Marker #):** _____ _____ _____

Invasive Plant Inventory Form

Invasive Plant Species: _____ **Inventory Date:** _____

Observer's Name: _____

County: _____ **Town:** _____

Site Location (directions & sketch map on back of form)**:** _____
_____
_____
_____

GPS Measurement: N: _____ **E:** _____

Contact Person (e.g.: landowner) **& Phone #** (if needed)**:** _____
_____

Location:
___ **Roadside** ___ **Facility**

Habitat:
___ **Ditch** ___ **River** ___ **Lake/Pond** ___ **Wetland** ___ **Upland** ___ **Stormwater Fac.**

Condition of Invasiveness:
___ **Spotty** ___ **Light** ___ **Dense** ___ **Dense Pockets**

Abundance (# individuals, square yards, acres, length, etc): _____

Invasives Description / Comments (sketch map on back of form):
_____
_____
_____

Photo #:	**Date:**	**Description:**
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

Control Recommendations:
_____
_____

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NYSDOT Database (Reference #): _____ DOT (Road/Marker #):

Invasive Plant Control/Evaluation Form

Invasive Plant Species: _____

Inventory Date: _____

Observer's Name: _____

_____

County: _____

Town: _____

Site Location (directions / sketch on back of form)**:**

_____

_____

_____

_____

GPS Measurement: N: _____ E: _____

Contact Person (e.g.: landowner) & Phone # (if needed):

_____

_____

_____

Dates Control Performed: _____ Who Performed Control_____

Control Method Used **(indicate where performed on sketch map on back of form)**:_____

_____

_____

Dates of Evaluation/Update: _____

Effectiveness of Control Methods **(indicate changes in invasive plant density on sketch map on back of form)**:_____

_____

_____

Recommendations for Future Management Efforts:

_____

_____

_____

Comments:

_____

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APPENDIX D

Overview of Common Integrated Roadside Vegetation Management or Integrated Vegetation Management Steps

One of the best overviews of Integrated Vegetation Management (IVM) plan components is a series of technical bulletins developed as a resource for vegetation managers seeking practical information on effective, environmentally sound methods for managing invasive species. The series was authored by the Bio-Integral Resource Center (BIRC) through a U.S. Environmental Protection Agency (EPA) grant. These bulletins have been published on the Internet at IPM Access through a separate EPA grant as a result of the EPA's interest in this type of information being made freely available to a wider audience. The following sections, addressing the principle components of IVM programs, are adapted from that resource:

- Gathering background information and conducting weed inventories.
- Setting management objectives.
- Establishing monitoring programs to inventory weed growth stages, locations, and acreage infested.
- Setting treatment action levels and treatment thresholds to determine if treatment is necessary.
- Using weed prevention measures and revegetation in your management plan.
- Applying effective, least-toxic management methods.
- Educating the public.
- Evaluating the program.

The goal of an IVM or Integrated Roadside Vegetation Management (IRVM) program is to keep noxious weed populations low enough to prevent unacceptable spread, damage, or annoyance, and to encourage desirable vegetation to permanently replace the weeds. Treatment occurs only when monitoring indicates thresholds have been reached and treatment is necessary. Several methods are selected from educational, biological, cultural, manual, mechanical, and least-toxic chemical control tactics and then integrated into a treatment program. IVM emphasizes revegetation with desirable plant species, as well as other actions that will prevent future weed infestations. When applied appropriately, the IVM process results in improved management, lower cost, greater ease of maintenance, and lower environmental impacts from control activities.

GATHERING BACKGROUND INFORMATION ON TARGET INVASIVES

Gathering as much information as possible about the biology and growth patterns of the target weed can assist and help direct management. Still other useful information can only be gathered on site and will be specific to your own problem situation. Information that will help staff to identify the target species may include:

- Common and scientific name
- Picture (as a young plant and in full seed/flower)—note if easily confused with others
- Annual or perennial
- Growth form and habits
- How tall the weed grows
- Timing of flowering or seed setting, which varies with latitude
- Distribution, geographical origin, and site preferences.

Life-cycle and lifespan information also helps determine proper treatment methods. Perennial weeds store nutrients underground and can access these reserves to resprout repeatedly. Maintenance staff may find the following valuable in determining appropriate treatment:

- How does the weed reproduce? If the weed spreads by seeds, note the flowering time, because control measures will usually occur before the flowers produce seeds to prevent another seed crop. Are a large number of seeds produced?
- What is the mechanism(s) of seed dispersal and how can it be reduced?

Also important are any special challenges the species presents in attempting to manage or control it. Knowing such challenges helps the design, construction, or maintenance manager to plan accordingly. For example, all invasives tend to have seeds that remain viable in the soil for many years.

- Can one small fragment regenerate an entire plant?
- Is the target weed found in sensitive areas such as wetlands or streamsides where treatment methods are limited?
- Is the weed resistant to certain types of control methods?
- Who are the people and the agencies that are concerned about this weed?
- What is the natural history of the site you are trying to manage (soil type, amount of rainfall, species of animals, and competitive vegetation present)?
- How is the land being used (present and future plans) and what is the history of land use?
- What is the history of weed control on the site?
- Is this a recent invasion or an old problem?

UNDERSTAND DAMAGE OR POTENTIAL THREAT

The damage caused to native plant communities by invasive species is extensive. Not only do weeds directly compete with native species for space, light, moisture, and nutrients, but they also have the ability to physically alter the structure or the nutrient cycling of a system, disrupting natural ecosystem function to which native communities are adapted.

SET MANAGEMENT OBJECTIVES

When setting management objectives, the weed manager will need to balance the resources available with the requirements of the law. The following questions may help in clarifying objectives:

- What are the legal requirements?
- What are the available resources (money, people, and time)?
- Which control strategies are best suited to the weed I am trying to manage and the area in which it occurs?
- What is the availability of biological control agents or grazing animals?
- What are the environmental considerations?
- What other people or agencies do I need to collaborate with?
- What kind of follow-up preventive measures will need to be implemented?
- What kind of public education is needed?
- What is the desired level of control (see below)? Can this level be sustained by my resources?

Levels of potential control include:

- *Containment*—keeping an established population of the weed in check so that the area infested by the weed does not increase. This strategy can be employed against newly invading weeds or well-established species. It is especially useful when time and money are in short supply or when the infestation is very large.
- *Reduction*—reducing the area covered by a weed or reducing the dominance of that weed. This strategy can also be used against new or established weeds; however, it requires more resources and more time than containment.
- *Eradication*—completely eliminating the weed from the management area. This strategy usually consumes the greatest amount of time and resources and is applicable mainly to newly invading weeds that are confined to a limited number of small areas.

SETTING TREATMENT ACTION LEVELS

Sufficient resources are seldom available. Weed management is a process that continues over many years, and weed managers are continually prioritizing treatment areas and balancing the priorities with their resources. This process is called "setting treatment action levels." When the weed population reaches an intolerable level, a department of transportation (DOT) takes action to treat it.

Two situations that increase the priority of a site are (1) the discovery of a small "outlier" population, a recent invasion from another area that must be taken care of soon to prevent a bigger problem later, or (2) the discovery that the weed population has become a threat to agriculture, native plants, food sources for wildlife, highway safety, water resources, etc. Inevitably there are areas that are lower in priority and will be tolerated for the short term. Complete eradication may not be practical unless the patches are very small. Moreover, to maintain populations of natural enemies, some individual plants must be permitted to persist.

Setting treatment thresholds includes prioritizing and balancing treatments with resources. Weeds will be treated when populations increase beyond a predetermined level. This level will largely depend on the characteristics of the site and weed. In some cases the level may be no weeds at all, and in other cases the number of weeds you can tolerate may be much greater.

ESTABLISHING A MONITORING PROGRAM

In IVM, monitoring is the repeated inspection of areas that may be subject to noxious weed problems. Written records will allow comparison of inspections over time to reveal how conditions are changing, especially whether noxious weed populations are increasing or decreasing.

- Focus limited monitoring resources on sites where problems are most likely to occur. Public sightings of new weed infestations may be encouraged through an education or incentive program (see *Educating Vegetation Management Personnel and the Public*).
- Maintain records of your monitoring activities. Creating standardized forms will make data collection easier and help remind you to gather all the information you need. Forms work best if they include labeled blanks for all pertinent information and allow the user to check or circle rather than having to write words or numbers. See examples of forms, which often include information such as the name(s) of the person(s) collecting the data; location and date of monitoring; a qualitative description of the vegetation, such as the names of the plants or types of plants (native vegetation, annual/perennial weeds, trees, etc.) and stage of growth (germinating, flowering, setting seed, etc.); and a quantitative description, such as percent cover, density, size of the patch, or, if possible, number of plants.
- Note special conditions such as unusual weather events and record treatment history, including information on

treatment applications (who, when, where, how, cost, difficulties, and successes). This will allow you to evaluate and fine tune treatments.

Monitoring efforts should be scheduled to coincide with critical life stages of the weed or its biological controls. If possible, plan monitoring sessions alongside other scheduled activities in the area to save time and labor. After treatment activities, and at the end of the season, schedule monitoring sessions to help you evaluate your program.

EVALUATE VEGETATION MANAGEMENT PROGRAM

At the end of the season, evaluate and fine-tune your program to improve it the next year. Some questions to ask at the end of the season might be (IVM Technical Bulletin, IVM Program Evaluation: members.efn.org/%7Eipmpa/noxevaluate.html).

- Were the objectives of the management program met?
- Were all the necessary components of the program actually developed?
- Were they integrated successfully? Were the right people involved in the integration?
- Which control methods seem to be working and which are not? Keep in mind that this is best answered over a span of years.
- Do some of these methods need fine-tuning?
- What kind of follow-up is needed next year?
- How can I best communicate this information?

Costs are central to a decision to continue an IVM program. It is important to keep in mind that the transition period to IVM will probably involve investing in the management of infested areas to achieve stable vegetation that will reduce management costs in future years. Native plants and other beneficial vegetation take years to establish. Although you may find that total annual costs drop during the first year of IVM, it is also possible that costs may increase somewhat; however, after two or three years costs should decline and stabilize below the historical average.

COST–BENEFIT INFORMATION REGARDING INVASIVE SPECIES CONTROL

A number of DOTs noted that access to information about the costs and benefits of treating invasive species could bolster their ability to get resources allocated to address the problem. A number of states, associations, and scientific entities have begun to compile these data.

- WSDOT *Comparison of Roadside Maintenance Practices—Impacts of Herbicide Use on Cost and Results*. Management without herbicides costs roughly double. (Washington State DOT, Cost Comparison—Vegetation Maintenance with and without Herbicides). www.wsdot.wa.gov/maintenance/vegetation/comparison.htm.
- *Northeastern States' Costs of Managing Invasive Species*, compiled by Ray Bouchard, Maine Department of Environmental Protection, Augusta.
- "Costly Interlopers: Introduced Species of Animals, Plants, and Microbes Cost the U.S. $123 billion a Year," *Scientific American*, Feb 15, 1999.
- Combating the Economic and Environmental Devastation from Invasive Species, Western Governors' Association, Dec. 2000.
- Economic and Environmental Threats of Alien Plant, Animal, and Microbe Invasions, Cornell University, *Ecosystems and Environment 84*, 2001, pp. 1–20.
- Evans, E.A., "Economic Dimensions of Invasive Species," *Choices Magazine: Food, Farm, and Resource Issues*, June 2003.
- Bergman, D.L., et al., "Economic Impact of Invasive Species to Wildlife Services' Cooperators," *Proceedings of the Third National Wildlife Research Center Special Symposium: Human Conflicts with Wildlife: Economic Considerations.*
- McCann, J.A., L.N. Arkin, and J.D. Williams, *Nonindigenous Aquatic and Selected Terrestrial Species of Florida: Status, Pathway, and Time of Introduction, Present Distribution, and Significant Ecological and Economic Effects*, National Biological Service, Gainesville, Fla.
- Noxious Weed Cost Share Program and ISDA 2002 Cost Share Program Accomplishments, Idaho State Department of Agriculture, Boise.
- "West Nile Virus Economic Impact, Louisiana," *Emerging Infectious Diseases*, Vol. 10, No. 10, Centers for Disease Control and Prevention, Oct. 2004. The 2002 Outbreak of West Nile Virus Cost Louisiana $20 Million: kplctv.com/AP (Sep. 28, 2004).
- "Potential Economic Losses Associated with Uncontrolled Nutria Populations in Maryland's Portion of the Chesapeake Bay," Maryland Department of Natural Resources, Annapolis, Nov. 2, 2004.
- "The Impact of Knapweed on Montana's Economy," North Dakota State University Agricultural Experiment Station, Fargo, July 1996.
- "Estimating Net Losses in Recreation Use Values from Non-Indigenous Invasive Weeds," Special Publication SP-03-10, University of Nevada–Reno, Cooperative Extension.
- "The Economic Costs of Delaying Invasive Weed Control: An Illustration Based on Nevada's Tall Whitetop Initiative," Special Publication SP-01-08, University of Nevada–Reno, Cooperative Extension.
- "The Estimated Costs of Treating Invasive Weeds in Elko County, Nevada," Fact Sheet FS003-41, University of Nevada–Reno, Cooperative Extension.
- "Economic Analysis of Containment Programs, Damages, and Production Losses from Noxious Weeds in Oregon," The Research Group, Corvallis, Oregon, for

Oregon Department of Agriculture, Plant Division, Noxious Weed Control Program, Nov. 2000.
- Impacts of Aquatic Nuisance Species Within the State of New York, New York Sea Grant.
- "Fire Ants Cost Texans Millions," Texas A&M University, Department of Entomology, Apr. 21, 2000.
- *Invasive Non-native Species: Background and Issues for Congress* (revised Nov. 25, 2002), Congressional Research Service, Washington, D.C.
- "Riparian Impacts—Invasive Plants Damage Green Zones Along Rivers and Streams," Montana Weed Control Association, Twin Bridges.
- "Rocky Mt Research Station: Foreign Weeds Feed Western Fires," Newspaper article on the problem of invasive plants and possible solutions, from the U.S. Forest Service.
- "The Spread of Invasive Weeds in Western Wildlands: A State of Biological Emergency," The Governor's Idaho Weed Summit, from the Bureau of Land Management.
- Weed Control on Conservation Reserve Program (CRP) Acres, Establishing Perennial Grasses on Former Cropland Presents a Challenge—weed control can be accomplished with herbicides, tillage, burning, mowing, and crop competition. The key to weed control is timeliness; from the University of Nebraska–Lincoln.
- Invasive Weeds in Rangelands: Species, Impacts, and Management—Rangeland and pastures comprise about 42% of the total land area of the United States. This abstract describes the effects found of more than 300 rangeland weeds in the United States, which cause an estimated loss of $2 billion annually, affecting the livestock industry, interfering with grazing, poisoning animals, increasing costs of managing and producing livestock, and reducing land value. Weed Science Society of America.
- Knapweed—Its cost to British Columbia (BC)—Several aspects of how knapweed (both diffuse knapweed (*Centaurea diffusa*) and spotted knapweed (*Centaurea biebersteinii*) infestations are causing major environmental deterioration and loss of beef production in the southern interior of British Columbia. BC Ministry of Agriculture, Food, and Fisheries.

APPENDIX E

State Department of Transportation Research Related to Invasive Species Control

Alabama	Mapping, control, and revegetation of cogongrass (*Imperata cylindrica*) Infestations on Alabama right-of-way
Alaska	Vetch (*Coronilla varia*) infestations in Alaska http://www.dot.state.ak.us/stwddes/research/assets/pdf/fhwa_ak_rd_02_11.pdf
California	Biocontrol research for control of cape ivy (*Delairea odorata*), star thistle (*Centaurea solstitialis*), and broom (*Cytisus scoparius*)
Connecticut	Phragmites (*Phragmites australis*) control
Indiana	Johnsongrass (*Sorghum halepense*) control
Iowa	1. Control of Japanese knotweed (*Polygonum cuspidatum*) with herbicides 2. Control of wild parsnip (*Pastinaca sativa*) with herbicide 3. Control of leafy spurge (*Euphorbia esula*) with herbicides 4. Control of burning bush (*Kochia scoparia*) with various herbicide mixes 5. Competitiveness of low-growing seed mixes in a median
Louisiana	Willow tree research
Maryland	25 year study of various control treatments for Canadian thistle (*Cirsium arvense*) and other thistles such as bull (*Cirsium vulgare*), musk (*Carduus nutans*), and plumeless thistles (*Carduus acanthoides*)
Minnesota	1. Prairie establishment and invasives control 2. Controlling leafy spurge (*Euphorbia esula*) and Canada thistle (*Cirsium arvense*) by competitive species 3. Management and control of Reed canary grass (*Phalaris arundinacea*) in restored wetlands 4. Facilitating native plant community establishment in wetlands following invasive plant removal 5. Biological control of Canada thistle (*Cirsium arvense*) in wetland prairie restoration 6. Canada thistle (*Cirsium arvense*) seed movement http://www.dot.state.mn.us/environment/publications.html—forestry

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North Carolina	Some of the research funded by NCDOT: 1. Increased options for weed management in the North Carolina Highway Wildflower Program 2. Vegetation management under guardrails for North Carolina roadsides 3. Herbicide options for weed management in the North Carolina Highway Wildflower Program 4. Weed control in wildflower beds 5. Control of Japanese knotweed (*Polygonum cuspidatem*) along the roadsides 6. Control of invasive plants using wet blade application techniques http://www.ncdot.org/planning/development/research/
Pennsylvania	Pennsylvania Roadside Research Project funded by PennDOT since 1985. Research on: 1. Integrated vegetation management 2. Management of specific weed species, such as tree-of-heaven (*Ailanthus altissima*), Japanese knotweed (*Polygonum cuspidatem*), and Canada thistle (*Cirsium arvense*) 3. Evaluation of alternative plant materials for roadside conservation plantings, such as native warm-season grasses and forbs 4. Evaluations of corridor management approaches, equipment, and herbicides http://rvm.cas.psu.edu/intropage.html
South Carolina	1. In-house bamboo control research project 2. Cogongrass (*Imperata cylindrical*) control
Texas	1. Ten compost projects 2. Seven native grass projects 3. Multiple herbicide research trials annually
Utah	1. Mapping 2. Biocontrol 3. Reduced mowing
Wyoming	1. Investigation of Species to Grow in Snowfence Areas, Report WY-94-04 2. Ecological Assessment and Evaluation of Snowfence Areas and Snowfence Mitigations, Report FHWA-WY-02/06F

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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