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Meeting the Challenge: Invasive Plants in Pacific Northwest Ecosystems

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Cover photography (clockwise from top):

Manual removal of garlic mustard (*Alliaria petiole*) (Karen J. Peterson)
Herbicide application to milk thistle (*Silybum marianum*) (Patricia A. MacLaren)
Seedhead weevil (*Larinus minutus*) for bio-control of diffuse knapweed (*Centaurea diffusa*) (Daniel L. Fagerlie)
Milk thistle (*Silybum marianum*) (Dennis Chambreau)
Scotch broom (*Cytisus scoparius*) (Joe Kraft)
Hoary alyssum (*Berteroa incana*) (Daniel L. Fagerlie)
Mechanical removal of Himalayan blackberry (*Rubus discolor*) (Ann Risvold)
Japanese knotweed (*Fallopia japonica*) (Kyle Strauss)
Center image: spotted knapweed (*Centaurea biebersteinii*) (www.invasive.org, Steve Dewey)

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Meeting the Challenge: Invasive Plants in Pacific Northwest Ecosystems

Timothy B. Harrington
and Sarah H. Reichard
Technical Editors

U.S. Department of Agriculture
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ABSTRACT

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During September 19-20, 2006, a conference was held at the University of Washington Botanic Gardens, Seattle, WA, with the title “Meeting the challenge: invasive plants in Pacific Northwest Ecosystems.” The mission of the conference was to create strategies and partnerships to understand and manage invasions of non-native plants in the Pacific Northwest. The audience included over 180 professionals, students, and citizens from public and private organizations responsible for monitoring, studying, or managing non-native invasive plants. This proceedings includes twenty-seven papers based on oral presentations at the conference plus a synthesis paper that summarizes workshop themes, discussions, and related information. Topics include early detection and rapid response; control techniques, biology, and impacts; management approaches; distribution and mapping of invasive plants; and partnerships, education, and outreach.

KEYWORDS: Non-native plants, invasive, exotic, weeds, vegetation management, early detection/rapid response, biological control, integrated management.

ENGLISH EQUIVALENTS

When you know:	Multiply by:	To find:
Degrees Celsius (°C)	(C*9/5) + 32	Degrees Fahrenheit (°F)
Centimeters (cm)	.3937	Inches (in)
Meters (m)	3.2808	Feet (ft)
Kilometers (km)	0.6214	Miles (m)
Square meters per hectare (m^2/ha)	4.3560	Square feet per acre (ft^2/ac)

ACKNOWLEDGMENTS

This conference was sponsored by USDA Forest Service, Pacific Northwest Research Station; University of Washington Botanic Gardens; The Nature Conservancy; and the Center for Invasive Plant Mangement. We would like to thank members of the Conference Steering Committee for their guidance during planning for the conference, the Science Advisory Committee for their assistance with selection and organization of conference presentations, and students from University of Washington and other colleges and universities who helped with conference logistics. Special thanks to Alaine Sommargren for assistance with manuscript formatting, to Steve Reutebuch for providing critical insight and support, and to our keynote speakers, John Randall, Les Mehrhoff, Ann Bartuska, and Doug Johnson, for sharing their knowledge, experiences, and inspiring ideas.

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CONFERENCE SYNTHESIS

Garden loosestrife (*Lysimachia vulgaris*) (King County Staff)

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MEETING THE CHALLENGE: INVASIVE PLANTS IN PACIFIC NORTHWEST ECOSYSTEMS

Sarah H. Reichard[1]

ABSTRACT

Compared to other parts of North America, the Pacific Northwest was settled relatively recently by humans of European origin. This more recent population growth and development has resulted in fewer plant invasions and therefore a greater opportunity to protect still relatively pristine wild areas. This can be achieved by prevention of new invasions, improved methods of control of existing invasive species, and better coordination of control work within geographic areas to prevent reinvasion within the areas. However, increased attention must be given to coordination and education over a wider area, such as the entire Pacific Northwest. This can be accomplished through non-profit organizations such as an Invasive Species Coalition, similar to efforts developed in other parts of the United States. These non-profits develop educational tools, serve to communicate about new invasions, and may coordinate control efforts over a broader geographic region.

KEYWORDS: Invasive plants, coordination, Exotic Pest Plant Councils.

INTRODUCTION

The Pacific Northwest (PNW) region of North America encompasses two countries and four states in the United States and one province in Canada (fig. 1). Coastal and Plains tribes of Native Americans occupied this region for centuries, but their population numbers prior to European visitation are unknown. Early explorers and fur trappers brought smallpox, measles, and influenza which caused waves of epidemics, decimating the populations before any type of census was done. There is evidence that these first peoples altered the landscape by burning areas to increase regrowth of some desirable species (Wray and Anderson 2003) and may even have moved some species into areas where they did not naturally occur (Larson 2006). However, this mostly either maintained a matrix of native species somewhat more diverse than would naturally have occurred or created small "gardens" of native species translocated somewhat out of their native context.

Although in the mid 1700s several European countries, including Russia, Spain, and England, recognized the rich natural resources in the PNW and sent ships to explore, the region was considered to be geographically remote from the rest of the continent and most areas did not see permanent settlements until well into the 1800s, less than two hundred years ago (Schwantes 1996). Contrast this with the east coast of North America, where St. Augustine, Florida was settled by the Spanish in 1565, Jamestown, Virginia was established by the English in 1620 and Plymouth, Massachusetts in 1620 by the Pilgrims. While human populations have steadily increased, especially in the coastal areas of the PNW, the colonization by large numbers is still fairly recent.

This region is therefore in a somewhat unusual situation on this continent in still having remaining landscapes which in many cases are minimally impacted by the destructive actions of humans. However, for those who

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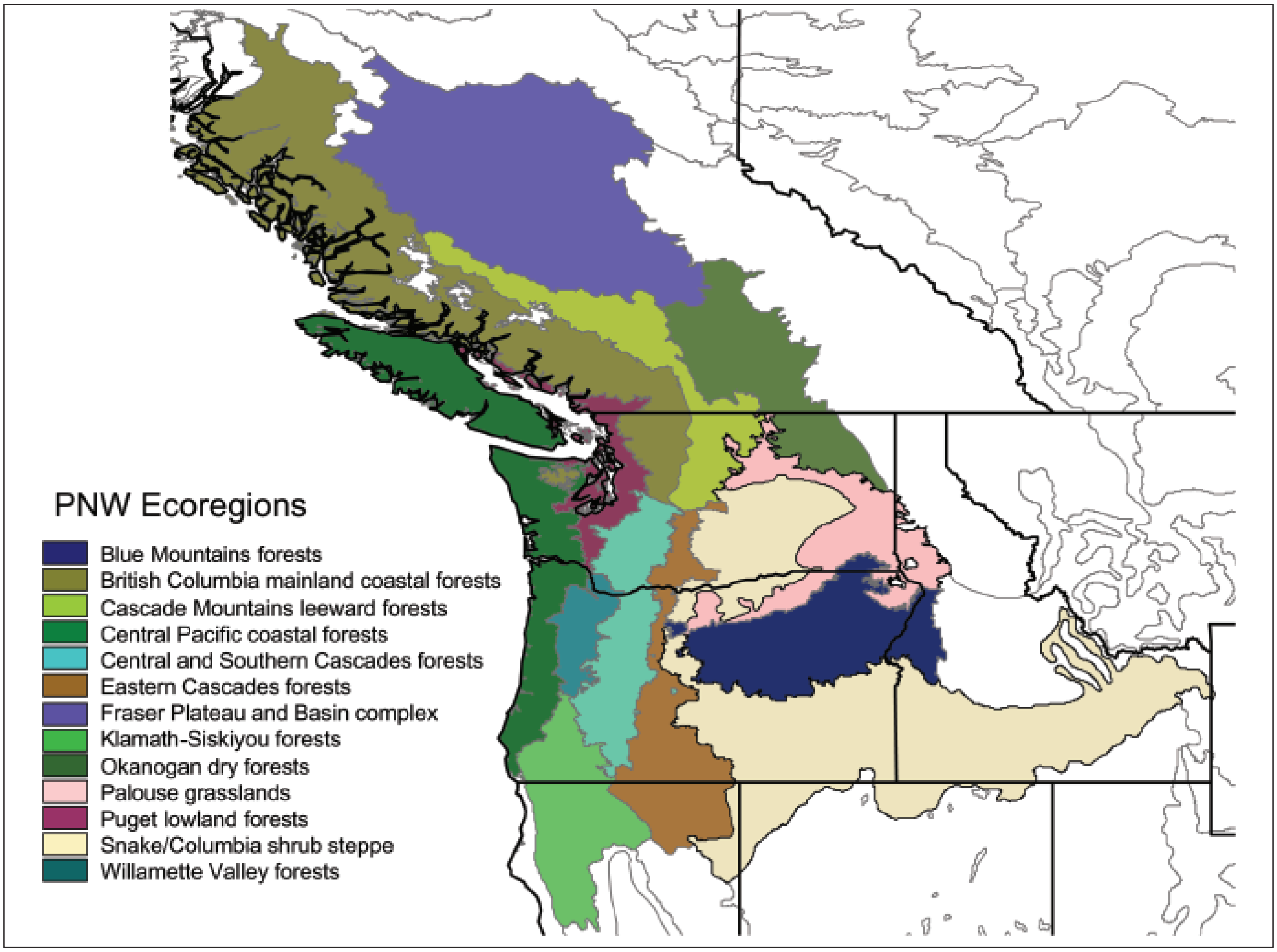

Figure 1—Pacific Northwest Ecosystems. Reprinted with permission from the University of Washington Press.

have lived in the PNW for more than two decades, the increase in urbanization, in particular, has been striking. With urbanization comes changes in hydrology, increases in disturbance, and the introduction of plants for ornamental or other uses (USDA Forest Service 2006). All these changes can lead to an increase in biological invasions of introduced plants (Reichard 2004).

Invasive plants can be defined as non-native species that have or potentially can establish in wildland or managed ecosystems, develop self-sustaining populations, and become visually dominant and/or disruptive to those ecosystems. Other terms are often applied, such as "exotic" or "alien," but these terms simply mean non-native and have other, sometimes value-laden meanings. "Weed" is another term often used. This simply means that the plants have a negative impact on a desired management objective, rather than an ecological meaning.

In the last twenty years we have learned much about the impacts of invasive species in wildlands. Such species compete with native species for essential resources, interrupting food webs. They alter nutrient cycling, hydrology, and disturbance regimes (Mack et al. 2000). Researchers in the PNW continue to discover new potential impacts of long-time invaders (Urgenson and Reichard 2007).

We still have the opportunity to reduce the introduction and spread of many species. While the United States and Canada federal governments must take on the role of controlling the entry of species either accidentally or for intentional uses in their countries, agencies, universities, and engaged citizens should play a key role in preventing the spread of existing and new invasive species and the control of those that have already established.

THE "INVASIVE SPECIES PROBLEM" WILL NOT GO AWAY

There are no estimates for how many new invasive species are being detected in the PNW, though each state or province regularly detects new species annually. A study done in California capitalized on the publication of the new Jepson Manual (Hickman 1993) and found that, while the rate of introduction of new species appeared to have slowed since earlier floras, 151 new species were established and another 101 reported earlier might no longer be present (Rejmánek and Randall 1993). They also found an increase in established species native to North and Central America and to South Africa, perhaps reflecting the introduction of new species by the horticulture industry. Another study, however, used herbarium specimens to verify species present in California and found an additional 315 species present that were not listed in the Jepson Manual. Of these, 58 were found in natural habitats, 53 in disturbed areas, 34 tenuously established, 13 in cultivated environments, 43 likely transitory, and 110 for which they could not conclusively determine invaded locations (Hrusa et al. 2002). While the PNW is less densely settled, it likely follows a similar trend of increasing introduction and establishment of invasive plants.

In 1997 a group under the auspices of a non-profit organization called the Pacific Northwest Exotic Pest Plant Council (see below) attempted to develop a list of all of the non-native species known to be surviving outside of cultivation in Oregon and Washington (PNW-EPPC, unpublished list). They found evidence of a total of 173 species invading, with 100 considered to be potentially or actually injurious to wildlands and another 73 present but less injurious. Twenty-three had nomenclatural and geographic issues that needed to be resolved. Since that time, a number of new species have been detected in wild populations, including notorious species invading other parts of the continent such as *Pueraria montana* var. *lobata* (Willd.) Maesen & S. Almeida (kudzu) and previously unknown aggressive species, such as *Ficaria verna* Huds. (fig buttercup).

These are indications that the PNW is following the same trend as California (Rejmanek and Randall 1993). For instance, the human population growth is expected to increase in the western United States overall by 45.8 percent between 2000 and 2030 (U.S. Census Bureau, http://www.census.gov/population/www/projections/projectionsagesex.html), with much of that almost certainly in the PNW. Given the increase in the human population in the area, with concomitant increases in community disturbance, we should expect the problem to increase in the coming years.

TOOLS FOR CONTROL AND PREVENTION

As we learn more about the biology of invaders, we are becoming increasingly sophisticated in controlling their spread. Earliest efforts at weed control in agricultural settings were largely achieved through tillage of the crops because prior to 1900 there were few other tools (Timmons 2005). In the late 1800s chemical methods increased and these methods expanded greatly in the mid-1900s when new chemical compounds to kill weeds and new technologies to deliver the chemicals were developed (Timmons 2005). New and safer compounds are continually being developed and other technologies are advancing. Biological control, the introduction of natural enemies (usually from the pest's native range) has become increasingly sophisticated, with rigorous testing to ensure no movement to plants of economic interest and native species. For instance, a classical biological control program to control knotweeds (*Fallopia japonica* (Houtt.) Dcne., *F. sachalinensis* (F. Schmidt Petrop.) L. P. Ronse Decraene, and *F.* × *bohemica* (Chrtek & Chrtková) J. P. Bailey) is using four insects identified for controlling these species in Great Britain and will be tested on about 60 species before experimental releases will be approved for the PNW (Grevstad et al. 2007).

Increasingly, researchers are finding that combining methods or treating the conditions at the site are sometimes the most effective and safe way to control invasive species.

For instance, many species respond to a herbicide treatment following mowing. This allows less herbicide to be used and provides good control results. Modifying the conditions at the site may control invasive species without herbicides at all. For instance, a combination of mulch and native species plantings successfully combined to control the shade-intolerant species, *Phalaris arundinacea* L. (reed canary grass) (L. Seebacher, personal communication). Nitrogen-fixing species often exploit nutrient-poor soils; amending soils with nitrogen-rich biosolids appears to reduce seedlings of nitrogen-fixing *Cytisus scoparius* (L.) Link (Scotch broom) (Shaben 2007)

As the numbers of invasive species increase and the resources to control them do not keep pace, an important component is strategically planning control efforts. For instance, invasive plants commonly invade lands owned by a matrix of landowners. Controlling a species only in part of the range, such as federal forest land, is a self-defeating process since reinvasion from lands owned by others will perpetuate the invasion. Increasingly Weed Management Areas (WMA) are being formed to address these multi-landowner invasions (DiTomaso et al. 2000). Weed Management Areas include public and private stakeholders who work collaboratively on surveying, implementing control work, developing monitoring plans, and educational materials (Scott 2007).

Even with WMA agreements increasing and new technologies, controlling invasive species is often discouraging. Surveys find vast acreage of species and contemplating such broad-scale control can be intimidating. One strategy is to develop a strict control plan for species considered to be a major threat and found in relatively small numbers across its range. Those species should be targeted for control and possibly for complete eradication. Other species may be widespread and only targeted for control if they threaten to invade a new area of high conservation value (Timmons and Owens 2001).

Another strategy for approaching weed management is to set definite performance goals for species or groups of species in a given year (Burke 2007). Such an approach would include determining a reasonable percentage of the population or the species range to be reduced within the year. If set reasonably, this gives workers a clear objective that is attainable and less demoralizing than the sense of failure that could result from targeting the entire range.

MEETING THE CHALLENGE

While control of existing invaders is essential to minimize harm to wild and other lands, there is growing acceptance that the most efficient way to manage invasions is to prevent the establishment of new species and new populations of species already present. In the latter case, WMA agreements can increase focus on species and facilitate communication about, and action on, new species. Educational work can increase public recognition of problem species, increasing the potential for new populations to be detected at an early and manageable stage of invasion. Models are being improved that might serve to guide land managers to likely sites of invasion by specific problem species (Jones et al. 2007).

The United States Department of Agriculture (USDA) regulates the introduction of new species into the country. While the Plant Protection Act of 2000 regulates which species are considered to be noxious in the country, resulting in quarantine, relatively few species are listed and most listed are already present in the country. Currently, there is little authority to restrict the entry of species based on their invasive potential, although those known to host pathogens or insects may be restricted. The USDA has proposed adding "plants for planting" to the policy regulating plant pests, which is known as Quarantine 37 or Q-37. This reflects a change in how species now enter the United States. Previously, planted material was introduced to the country mostly as propagating stock, with the introduction of 100 or fewer plants or seeds, so the entry of plants was fairly slow. Today, however, offshore nurseries are increasingly shipping plants ready for the consumer into the country. The plants are now only actionable if insects or pathogens are found. Under the proposed changes in Q-37 species would be allowed in unless they were considered "Not Authorized for Import Pending Risk Analysis" or NAPRA. Species that fit the definition of a noxious weed under the Plant Protection Act of 2000 or the International Plant Protection Convention and are not known to occur in

Figure 2—Regions of the United States currently with cooperative pest plant councils or coalitions. Reprinted with permission from the National Association of Exotic Pest Plant Councils.

the United States would be considered to be NAPRA and therefore subject to screening (Tschanz and Lehtonen 2005).

While the USDA and Canada's Ministry of Agriculture and Lands appropriately have the responsibility of identifying new potential pests at their country's borders, it is inevitable that species will become invasive despite their best efforts. Therefore, detection of and response to new species must be done on a more regional and local level. Dealing with the invasive plant problem requires partnerships to quickly find new invasive species, share information on control, and develop effective educational tools. Throughout the United States non-profits, often labeled as "Exotic Pest Plant Councils" (EPPC) or "Invasive Plant Councils" (IPC) are being formed to facilitate these partnerships. The first Exotic Pest Plant Council was formed in Florida more than 20 years ago to encourage communication between land management agencies working on invasive plants. In 1992 California expanded on this idea by making membership open to all agencies and individuals interested in this emerging environmental issue. Currently there are such networks throughout mostly the eastern part of the U.S. (fig. 2). These networks have joined together to form a national oversight group, the National Organization of Exotic Pest Plant Councils (http://www.naeppc.org).

In the mid 1990s there was an effort to start the PNW EPPC. A board was formed, by-laws written and approved, 501 (c)(3) exemption status was granted by the U.S. Internal Revenue Service, and there were a few newsletters, meetings, and activities. However, by 1998 it was no longer active, mostly due to a small initial founder membership that moved on to other jobs and projects (L. Whiteaker, personal communication).

Across the country the EPPC/IPCs have done a number of things that have facilitated work on plant invasions in their region. Here are a few examples of what a PNW network might be able to do:

- Form working groups on particular taxa
- Write grant proposals and administer funds to those working on a project

- Hold regular conferences
- Produce carefully evaluated lists of plants of concern in the region (note: this was done for Washington and Oregon by the PNW EPPC in 1997 but needs major revision)
- Work with industries, such as the nursery industry, to prevent invasions through industry pathways
- Produce publications and educational materials that can be distributed through the network to a wide audience
- Foster communication
- Provide an early detection warning system

Much of the organizational work for the PNW-EPPC (by-laws, status with the United States Internal Revenue Service, etc.) was done in the earlier effort. To restart the network would require forming a board of directors/leadership council, working on developing membership, deciding priorities for the first few years, and searching for funding to increase stability. Other decisions would include deciding if states should have individual organizations that collaborate as a regional network or if there should be a single regional network, and what the region would encompass.

The Pacific Northwest still has vast acreage of mostly unspoiled wildlands. With increasing development it is critical that we take action to protect our resources. While we must continue to effectively and creatively control the invasions of current invasive species, we need better tools to prevent the spread of current species into new areas and the introduction of new species into the region. Better communication and coordination throughout the region will help achieve these goals. The conference that resulted in these proceedings was a good first step. The question now becomes: how do we continue what the conference began?

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EARLY DETECTION AND RAPID RESPONSE

Robert geranium (*Geranium robertianum*) (Katie Barndt)

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INVASIVE SPECIES EARLY DETECTION PROTOCOL DEVELOPMENT IN THE NATIONAL PARKS: INTEGRATING ALL THE PIECES

Susan O'Neil[1], Brad Welch[2], Penelope Latham[3], and Daniel Sarr[4]

ABSTRACT

The National Park Service Inventory & Monitoring Program, in collaboration with the U.S. Geological Survey Status and Trends Program, compiled a handbook to provide guidance and insight to parks and other natural areas engaged in developing early detection monitoring protocols for invasive plants. While several rapid response frameworks exist, there is no consistent or comprehensive guidance informing the active detection of non-native plants early in the invasion process. There are many approaches and often little consensus regarding how to develop efficient early detection monitoring; however, because of the pervasiveness of this issue and the fact that invasive species are not place bound (i.e., they freely cross ecological boundaries, states, nations, and continents), we have tried to provide guidance to encourage a consistent approach to monitoring. We hope this will result in an efficient, effective tool for combating the considerable threat of invasive plants to native ecosystems and biodiversity in national parks and elsewhere. We recognize that the task of detecting invasive species when populations are small is complex and will require a flexible approach to meet varying objectives, financial situations, and ecological conditions of individual parks and natural areas.

KEYWORDS: Early detection, invasive species, monitoring, modeling, sample design, protocols.

INTRODUCTION

In 1996, the Director of the National Park Service (NPS) distributed the first NPS plan for managing non-native, invasive plants with six key strategies identified including preventing invasions and conducting inventory and monitoring of non-native plants. In 2000, a detailed action plan was drafted, with a revision in 2006, which re-emphasized the role of prevention and early detection/rapid response. The Inventory & Monitoring (I&M) Program, which was established in 1998 as part of the Natural Resource Challenge National Parks Omnibus Management Act, organized 270 national parks into 32 networks to inventory resources and conduct long-term monitoring of key indicators, used to monitor park resources. Invasive species continue to rank high among I&M networks for long-term monitoring.

Early detection was selected as a primary focus for invasive species monitoring because, along with rapid response, it is a key strategy for successful management of invasive species. Eradication efforts are most successful on small infestations. By tracking new species and new infestations, parks may begin to understand the strategies and invasion patterns which will allow for improved management actions. Rejmanek and Pitcairn (2002) determined that eradication success is likely when the infestation is less

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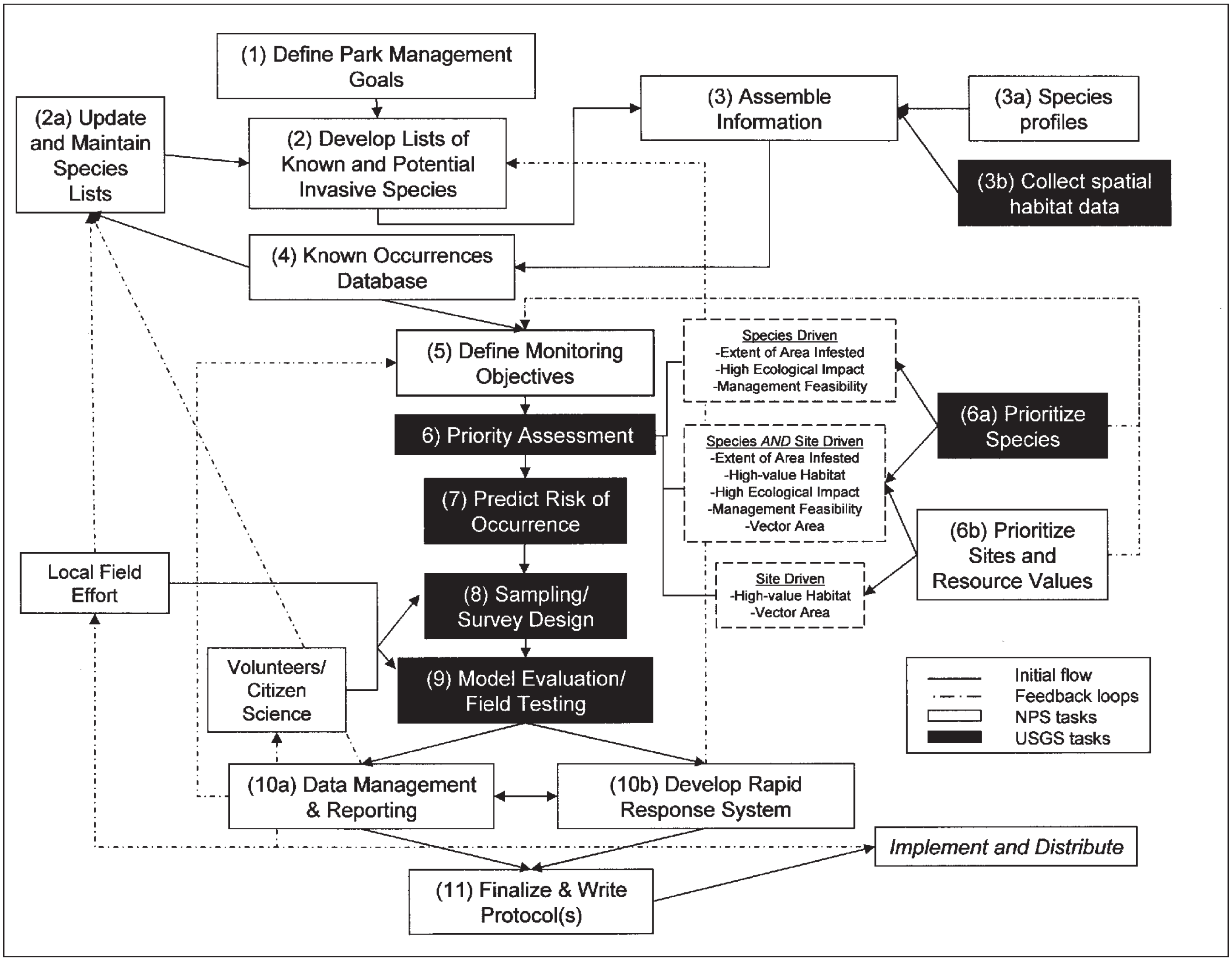

Figure 1—Elements of an invasive species early detection monitoring program in National Parks.

than 1 hectare (ha), and that success of eradication is unlikely when the infestation is over 1000 ha. Too often early detection is conducted passively in parks. Managers rely on erratic reports from visitors, maintenance staff, and backcountry rangers as the source of information to trigger management action. The nature of this approach requires spontaneous decisions to be made about allocation of staff time and other resources, directing them away from current projects toward unexpected and unconfirmed issues. Alternatively, active detection methods may be employed such that managers respond rapidly to predictable, confirmed reports in a timely and cost-effective manner. To this end, NPS and the United States Geological Survey (USGS) Status and Trends Program set out to create a handbook to assist managers in developing an early detection program. The document provides guidance for natural resource managers wishing to detect invasive plants early through an active, directed monitoring program.

ORGANIZATION AND CONTENTS OF THE HANDBOOK

Chapters 1-3 (Section 1) introduce the text, summarize dominant invasion theories relevant to this text, and outline the key components required to implement a successful early detection monitoring program. Chapters 4-10 (Section

2) address each of the early detection steps in detail including setting goals and objectives, acquiring appropriate information, choosing analytical processes, conducting evaluation and assessment, and implementing detection methods. Chapters 11-15 (Section 3) provide applications of early detection principles within the context of the Klamath, San Francisco, and Heartland NPS I&M Networks. Two chapters present information from the Klamath Network: Chapter 11 shares insights with respect to early detection protocol development across multiple parks, and Chapter 12 offers an approach to probabilistic predictive modeling of invasive plants with detailed examples from Lava Beds National Monument. The San Francisco Network presents a small park example using volunteers. The Heartland Network highlights a protocol for integrating early detection and long-term trends monitoring across large and small parks. An example using remotely sensed and geographically referenced data for predicting the risk of occurrence for target species in Big Bend National Park is presented in Chapter 13. Subsequent materials include citations, a glossary, detailed reports from participating researchers, and a protocol template which meets NPS I&M program standards. The protocol template will be useful for those who may be required to document their specific early detection procedures. Cited materials and sources of additional information appear in the bibliography and are grouped by chapter.

The handbook also has a Quick Start guide to direct readers to specific chapters and text relevant to their needs. Each chapter was written by a U.S. Geological Survey (USGS) researcher(s) or NPS managers/researchers. Decision trees and flow charts assist the reader in deciding what methods to choose and when to employ them in several chapters. The various steps (and thus chapters) in Section 2 are meant to follow a conceptual model developed by the I&M program that encapsulates the idealized components of an early detection program (Fig. 1). A park or network may decide to implement only a few of the relevant components. The handbook is written in a modular format to accommodate use of individual chapters. It may also be approached in a linear fashion, as a sequence of steps leading to a comprehensive approach to early detection.

This handbook is intended to be a living document which will be updated regularly via an electronic internet copy as new materials become available. In particular, we anticipate specific protocols developed by individual I&M networks will be linked to this document to provide readers with a range of specific implementation examples. Although this document has been designed with the NPS I&M networks and parks in mind, it undoubtedly will have broad application for natural areas professionals everywhere wanting to improve invasive plant management strategies.

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DEVELOPING EARLY DETECTION NETWORKS TO ABATE THE INVASIVE PLANT SPECIES THREAT

Kyle Strauss[1]

ABSTRACT

Prevention and Early Detection & Rapid Response (EDRR) practices are the most effective strategies for managing the invasive plant species threat over the long-term and at large-scales. When new invasive plant species are immediately detected and identified, and rapid responses are taken to contain and eradicate those new infestations, environmental and economic damages and subsequent impacts can be significantly mitigated.

EDRR programs can take different forms depending on the scale of the project site. An EDRR program can be constructed and implemented at both the site and at larger state/regional scales. The up and coming EDRR network for The Nature Conservancy in Oregon is utilizing the site approach at several locations throughout the state. The Oregon Chapter of the Conservancy is planning to learn from other existing EDRR programs from around the country.

The Nature Conservancy's Maryland/Washington D.C. Chapter Weed Watchers/Weed Busters program uses volunteer efforts to locate new infestations, which are then reported to Conservancy staff. Once the invasive species is prioritized and a control strategy is created, volunteers then carry out the rapid response effort. As of 2005, over 50 volunteers had worked on 19 new invasive species at five preserves. For more information on this program visit http://tncweeds.ucdavis.edu/outreach.html.

A larger scale EDRR project in New England, called IPANE, which stands for Invasive Plant Atlas of New England, is a great example of a large scale EDRR network. IPANE is a regional effort to combat invasive plant species that also utilizes volunteer efforts. IPANE also benefits from paid staff thanks to funding that allows the program to work on a larger scale. The website for IPANE contains invasive plant information, volunteer directions, distribution maps, and much more. It can be found at http://nbii-nin.ciesin.columbia.edu/ipane/index.htm.

EDRR work with the Oregon Chapter of The Nature Conservancy will begin in the fall of 2006. EDRR Coordinator Tania Siemens can be reached at tsiemens@tnc.org.

KEYWORDS: Early detection, rapid response, invasive.

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THE FIRST LINE OF DEFENSE: INTERCEPTIONS OF FEDERAL NOXIOUS WEED SEEDS IN WASHINGTON

Margaret Smither-Kopperl[1]

ABSTRACT

The Plant Protection Act defines a noxious weed and provides a list of species that are prohibited or restricted from entering the United States. Under the provisions of the Plant Protection Act and Federal Seed Act there is zero tolerance for entry of designated Federal Noxious Weeds (FNW). Responsibility for interception, identification and exclusion of these species at our borders is shared between the Department of Homeland Security, Customs and Border Protection (DHS-CBP) and the U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS). CBP Agriculture Specialists make interceptions from marine/air cargo and baggage at ports and border crossings. Identification is provided by the Botanist Identifiers of USDA-APHIS and the National Identification Service. During 2005 and 2006, FNW seeds were intercepted at the Port of Seattle, SeaTac International Airport and the Canadian border. The incidence and frequency of interceptions varied with location. At the Port of Puget Sound, from September 2005 through August 2006, a total of 799 botanical interceptions were processed. Of these, 44 or 5.5 percent of the total number of plant interceptions were FNW. The most frequently intercepted FNW seeds were *Imperata cylindrica* (L.) P. Beauv. (cogongrass), *Pennisetum polystachion* (L.) Schult. (mission grass), and *Tridax procumbens* L. (coat buttons). At SeaTac Airport the most frequent interceptions were *Ipomoea aquatica* Forssk. (water spinach) and *Heracleum mantegazzianum* Sommier & Levier (giant hogweed). At the Canadian border, Blaine, the most frequent interceptions were of *Asphodelus fistulosus* L. (onionweed), a frequent contaminant of cumin, and *Oryza* sp. (red rice). Shipments containing a FNW seed are refused entry, unless the seeds can be removed or separated and/or devitalized. Interceptions of FNW seeds from passenger baggage for consumption and propa-gation are confiscated and destroyed.

KEYWORDS: Import, noxious weed, commodity, risk pathway.

INTRODUCTION

The responsibility for preventing the introductions of Federal Noxious Weeds (FNW) is shared jointly by two government agencies: United States Department of Agriculture – Animal and Plant Health Inspection Service – Plant Protection and Quarantine (USDA-APHIS-PPQ) and Department of Homeland Security – Customs and Border Protection (DHS-CBP). Prior to the formation of DHS the responsibility was held solely by USDA. The separation of responsibilities is found in a Memorandum of Agreement (DHS 2003). Amongst the responsibilities of USDA-APHIS-PPQ are to: a) inspect propagative material entering the U.S.; b) identify intercepted pests; c) recommend treatment; and d) if applicable, apply or monitor treatment. The responsibilities of DHS-CBP include: a) inspection of international aircraft, vessels, and vehicles and passengers; b) inspection of air and marine cargo; and c) the procedure to refer intercepted pest species to PPQ for identification and treatment recommendations.

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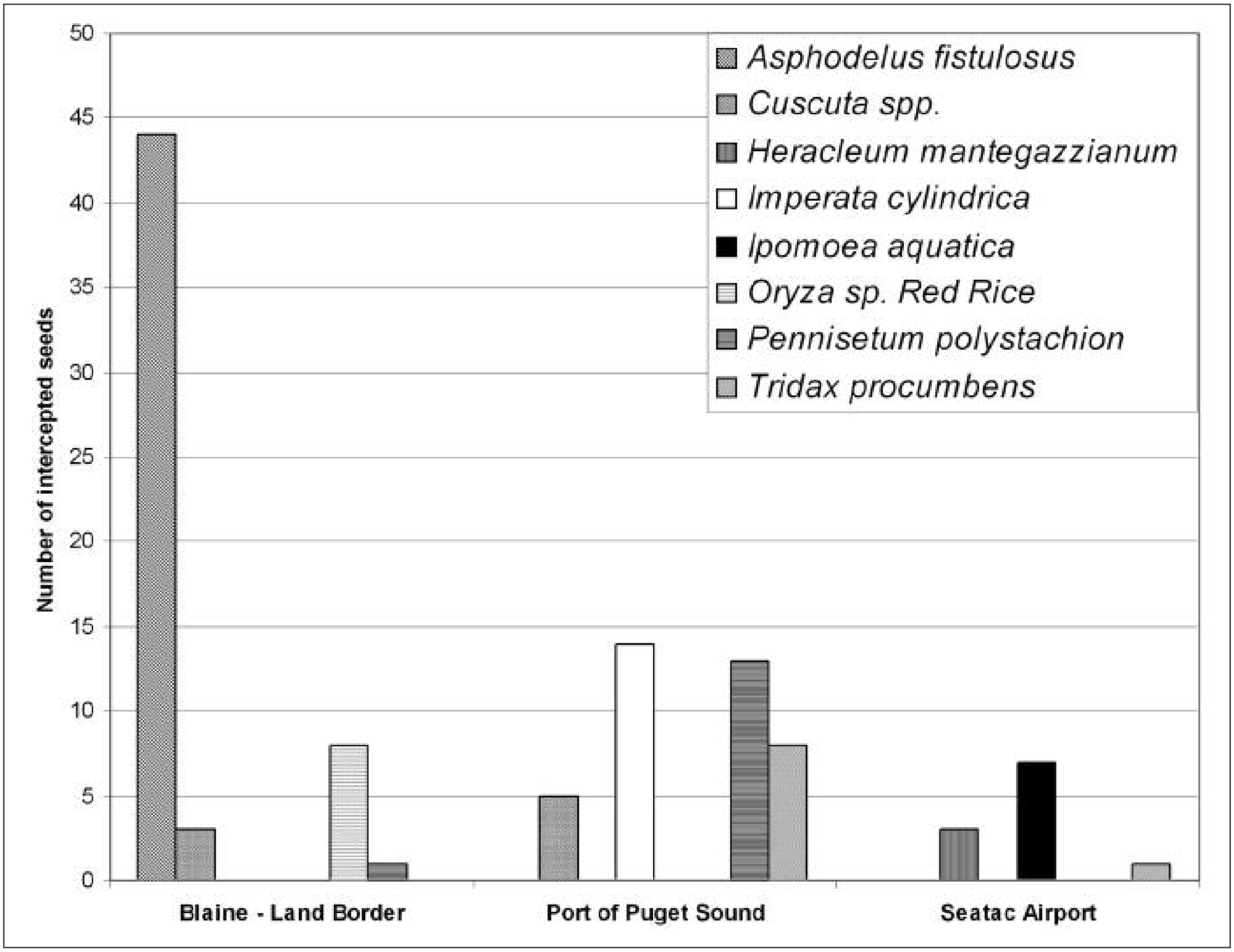

Figure 1—Interceptions of Federal Noxious Weed Seeds in Washington from September 1, 2005 to August 31, 2006.

The authority for USDA-APHIS to regulate noxious weeds is provided by the Plant Protection Act of 2000, which supersedes previous regulations. Under the Act a noxious weed is defined quite broadly as “any plant or plant product that can directly or indirectly injure or cause damage to crops (including nursery stock or plant products), livestock, poultry or other interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment.” In addition, the Federal Seed Act regulates interstate and foreign commerce in seeds, and addresses “noxious weed seeds” that may be present in agricultural or vegetable seed (USDA 1998). Noxious Weeds may be designated as either “Federal” or “State” Noxious Weeds. USDA-APHIS has authority to regulate only FNW.

The list of FNW includes weeds not currently known to be present, or with limited distribution within the U.S., that have been determined to pose a high risk to agriculture and the environment (USDA 2006). The list is constantly reviewed and updated as the need arises. There is zero tolerance for seeds of FNW; if a seed is found, entry of the associated commodity is prohibited. There are exceptions for mitigating the risk of noxious weed contamination in cargo. These can be used only if the commodity can be

Table 1—Interceptions of Federal Noxious Weeds in Washington during July 2006

Port Location	Organism	Country of Shipment Origin	Commodity
Port of Puget Sound	*Imperata cylindrica* cogongrass	Vietnam	Pottery
		Australia	Machinery
		China	Household goods
		Philippines	Vehicle
		Japan	Used tires
Port of Puget Sound	*Pennisetum polystachion* mission grass	Vietnam	Pottery
		Turkey	Marble
Port of Puget Sound	*Saccharum spontaneum* wild sugarcane	Turkey	Marble
Port of Puget Sound	*Tridax procumbens* coat buttons	Vietnam	Pottery
		Thailand	Military vehicles
Seattle Plant Inspection Station	*Alternanthera sessilis* sessile joyweed	Singapore	Aquatic plants
Seattle Passenger	*Ipomoea aquatica* water spinach	Cambodia	Baggage
Blaine	*Asphodeus fistulosus* onionweed	Canada	Cumin seed
Blaine	*Oryza* sp. red rice	Canada	Rice - *Oryza sativa*

freed from the seed contaminants and the contaminants can be devitalized by an appropriate treatment; if grinding is appropriate, this method may be used. For any treatment of an imported commodity, the importer must be in agreement and pays the costs. This can result in a significant cost to the importer.

USDA-APHIS-PPQ does allow movement of FNW into the United States, or between States, under specific circumstances such as research. Movement is allowed under permit (PPQ form 526) only where explicit conditions can be met.

Within Washington State, USDA-APHIS-PPQ inspects propagative plant material under permit at the Seattle Plant Inspection Station. CBP Agriculture Specialists submit interceptions from three locations: a) Maritime cargo, inspected at the Port of Puget Sound, both Seattle and Tacoma; b) SeaTac Airport, including Air Cargo and international passenger baggage; c) Blaine, the land border with Canada. Identification of plant material is conducted at the Seattle Plant Inspection Station and plant material may also be sent to the USDA-APHIS-PPQ National Identification Service Botany Identifiers in Beltsville, MD.

INTERCEPTIONS OF FEDERAL NOXIOUS WEED SEEDS

The incidence and frequency of interceptions varies with location. Federal Noxious Weed seeds were intercepted at the Port of Puget Sound, SeaTac Airport and the Canadian Border during 2005 and 2006 (fig. 1).

At the Port of Puget Sound, from September 2005 through August 2006, a total of 799 plant interceptions were processed. Of these, 44 or 5.5 percent of the total number of plant interceptions were FNW. These were primarily wind dispersed seeds in a variety of cargo types. The most frequently intercepted FNW seeds were *Imperata cylindrica* (L.) P. Beauv. (cogongrass), *Pennisetum polystachion* (L.) Schult. (mission grass), and *Tridax procumbens* L. (coat buttons) (fig. 1). These seeds were found in shipments from East Asia, Australia and New Zealand, and the Mediterranean region. The seeds are wind dispersed and found in a variety of cargo types (table 1). Seeds of *Cuscuta* spp. (dodder) a parasitic plant were intercepted as a seed contaminant in *Guizottia abyssinica* (niger) seed.

Those FNW seeds intercepted in passenger baggage are commonly for personal consumption. At SeaTac Airport the most frequent interceptions were *Ipomoea aquatica* Forssk. (water spinach), and *Heracleum mantegazzianum* Sommier & Levier (giant hogweed). At the Canadian border, Blaine, the most frequent interceptions were of *Asphodelus fistulosus* L. (onionweed), a frequent contaminant of cumin, and *Oryza* sp. (red rice), a contaminant of rice. *Cuscuta* spp. (dodder) were also intercepted as a component of Chinese herbal medicine.

RISK PATHWAYS AND ENTRY PREVENTION

The most common FNW in marine cargo were of wind dispersed seeds found in shipments of products such as pottery, marble and granite. These products may remain open to the environment prior to shipping, which allows the seeds to settle and contaminate the cargo. All FNW seeds intercepted in marine cargo at the Port of Puget Sound are prohibited. The cost of destruction or treatment is borne by the importer and this acts as a significant deterrent. It is in their interests to ensure that their shipments are clean and free of FNW.

Passenger baggage is a significant risk pathway for entry of FNW. At SeaTac Airport the most frequent interceptions were *Ipomoea aquatica* Forssk. (water spinach) carried by passengers from East Asia, including China, Cambodia and Vietnam. The seeds were intended for propagation and consumption. *Heracleum mantegazzianum* Sommier & Levier (giant hogweed) seeds were intercepted in baggage of passengers from the Middle East, particularly Iran, where the seeds are used as a spice. At Blaine, *Asphodelus fistulosus* L. is a frequent contaminant of cumin originating in India. The large number of travelers entering the U.S. from Asia makes passenger baggage a major risk pathway for entry of FNW. When these seeds are intercepted in baggage they are confiscated and destroyed.

The combined actions of DHS-CBP to inspect cargo and intercept potential weed pests, and USDA-APHIS-PPQ to inspect propagative material and to identify interceptions and recommend treatment, results in the exclusion of significant numbers of FNW from the State of Washington. At other air- and seaports the same activities are being undertaken to support the mission to detect, identify and prohibit entry of FNW into the United States.

ACKNOWLEDGMENTS

I wish to thank Mae Ikawa, Barbara Chambers and Marla Cazier-Mosely (USDA-APHIS-PPQ) and Susan Spinella (DHS-CBP) for their support. Also thanks to Rodney Young and Gayle van de Kerckhove for critically reviewing the manuscript.

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SUMMARY OF THE NATIONAL ENVIRONMENTAL POLICY ACT APPROACH FOR EARLY DETECTION/ RAPID RESPONSE TO INVASIVE PLANTS ON THE OLYMPIC NATIONAL FOREST

Rochelle Desser[1]

ABSTRACT

Early detection/rapid response (EDRR) in invasive plant management is intended to identify and address invasive plant populations as quickly as possible. The economic and ecological costs of treatment increase with population size and effectiveness of treatment decreases. The sooner a target species is detected and treated the more likely it will be controlled. However, analysis for EDRR provides challenges to land managers striving to meet the requirements for site-specific analysis under the National Environmental Policy Act (NEPA). An interdisciplinary team working for Olympic National Forest developed a process that meets the site-specificity requirements of NEPA and provides flexibility to respond to current and unpredictable new infestations that occur within the next five to fifteen years.

KEYWORDS: Invasive plant management, early detection/rapid response, National Environmental Policy Act, Olympic National Forest.

THE DILEMMA

The National Environmental Policy Act (NEPA) and United States Forest Service (USFS) Implementing Regulations (FSH 1909.15) outline the process the agency must use to consider and disclose the site-specific impacts of land management programs and projects. Each "site" is generally mapped, and the proposed actions for that site are described at a fine scale. However, invasive plants are dynamic – their rate and/or direction of spread cannot be precisely predicted.

Analysis under NEPA often takes months or years to complete. The rapid potential for change is greater with invasive plants than other Forest Service endeavors such as timber or recreation management. This poses challenges for land managers attempting to treat invasive plants that become introduced, established or identified during the time taken to complete a site-specific analysis under traditional NEPA procedures.

THE PREMISE

The premise of the Olympic National Forest NEPA approach for analysis of early detection/rapid response (EDRR) is that similar treatments on similar sites will have similar environmental impacts. Site-specificity is ensured by focusing the analysis on treatments necessary to respond to the current inventory of invasive plants. Site-specific conditions found in the current inventory were classified based on their sensitivity to the effects of treatments (for example, proximity to water, wildlife habitat, places where people gather, etc.). Project design criteria were then developed to limit the extent of treatment spatially and temporally, depending on sensitivity to impacts for each site type. The intent was for the project design criteria to apply to new detections located anytime during the life of the project. Thus, the effects of treatment were predictable, even if the precise time and place the treatments will occur were unpredictable.

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An implementation planning process has also been developed to ensure that project design criteria are appropriately applied. This approach follows guidance regarding changes made to a proposal after a decision is documented under NEPA.

THE PROCESS

1. Known vectors of invasive plant spread were inventoried across the entire Olympic National Forest. Anecdotal information was added and inventory information was extrapolated into areas that were not surveyed on the ground. Road systems and other invasive plant vectors were mapped and predictable rates of spread were applied to estimates of acreage needing treatment. Many factors were considered in the initial treatment proposal including priority, intensity and objective of treatment.
2. The Olympic National Forest was divided into treatment areas, and site conditions throughout the treatment areas were evaluated.
3. The interdisciplinary analysis team considered the effects of invasive plant control methods known to be needed to treat the full range of situations found or predicted on the Forest. In the case of the Olympic National Forest, this included broadcast, spot and selective methods of herbicide application, as well as manual and mechanical non-herbicide methods (e.g., mowing, hand pulling, and cut stump treatments).
4. Project design criteria were developed to provide analytical sideboards as needed. Limits were placed on the future selection, rate and extent of herbicide use to reduce the potential intensity and magnitude of treatment impacts. The prescription criteria add layers of caution to invasive plant treatments to ensure “the cure is not worse than the disease.”
5. Buffers were established to limit the rate, application method, or selection of herbicides near surface water bodies. Buffers were also established to protect native botanical species of local interest.
6. Restoration of treated sites (e.g., mulching, seeding, and planting to restore native plant communities and/or resist reintroduction of invasive plants) was included as part of the prescription criteria.
7. The Environmental Impact Statement (EIS) documented the process the Forest will use to determine appropriate treatment of new detections.

CONCLUSION

The EIS disclosed the effects of treating invasive plants given the full range of situations found or predicted across the entire Olympic National Forest. The analysis was site-specific and provided flexibility to respond to rapidly changing site conditions. Project design criteria compensated for uncertainties of treatment under EDRR.

CONTROL TECHNIQUES, BIOLOGY, AND IMPACTS

English holly (*Ilex aquifolium*) (Katie Barndt)

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DEVELOPING A BIOLOGICAL CONTROL PROGRAM FOR INVASIVE KNOTWEEDS (*FALLOPIA* SPP.)

Fritzi Grevstad[1], Richard Reardon[2], Bernd Blossey[3], and Richard Shaw[4]

ABSTRACT

A classical biological control program is being developed for Japanese and giant knotweeds (*Fallopia japonica* (Houttuyn) Ronse Decraene and *F. sachalinensis* (F. Schmidt) Ronse Decaene) and their hybrid (F. × *bohemica* (Chrtek & Chrtková) J.P. Bailey) in North America. In classical biological control, host-specific natural enemies from the weed's native range are introduced with the intent of establishing a permanent population that will provide control of the weed. The steps in developing a biological control program include identifying the problem, surveys of existing natural enemies, foreign exploration for new natural enemies (candidate biocontrol agents) from the weed's native range, host specificity testing of candidate agents, safety review and permitting, and if approved, release and monitoring of biocontrol agents and their impacts. Biological control provides a highly economical and sustainable approach to managing widespread weeds. Provided that the proper steps are taken to ensure host-specific agents, biological control of weeds can be implemented with a high level of safety (McEvoy 1996, Pemberton 2000).

KEYWORDS: *Fallopia sachalinensis*, *Fallopia japonica*, *Fallopia* × *bohemica*, biological control, knotweed.

INTRODUCTION

Invasive knotweeds are widely recognized as an environmental problem. They are listed among the "world's worst invasive species" by the World Conservation Union and are listed as noxious in seven states including Oregon and Washington. In these states, they are slated for control, but generally considered too widespread for regional eradication. All three invasive knotweeds have spread most aggressively along rivers and streams, but they are capable of occupying an alarming diversity of habitats. Knotweeds crowd out native plants through shading and nutrient competition. The dense stands have no known value for wildlife, harbor few invertebrates, and can prevent trees from growing near the streams. Knotweeds are reported to cause increased erosion (Child et al. 1992) as well as increased flooding (Welsh Development Agency 1991) and their forceful roots and rhizomes can cause damage to road surfaces and building foundations (Shaw and Seiger 2002). Finally, knotweeds are a recreational nuisance, limiting stream access for uses such as fishing and boating.

IDENTIFICATION OF CANDIDATE BIOCONTROLS FOR KNOTWEED

A possible contributor to the invasiveness of knotweeds is a lack of existing natural enemies in the introduced range. In 2003 and 2004, we carried out surveys of existing natural enemies of knotweed in the states of New York, Oregon,

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and Washington. Additional surveys were carried out in Alaska in 2005 (J. MacIver, pers. comm.). More than 50 different species of herbivorous insects were found. However, very few of these were found repeatedly or were clearly using knotweed as a host for feeding and reproduction.

Notable East Coast natural enemies include Japanese beetle (*Popillia japonica*) and an unidentified pathogen. On the West Coast, notable herbivores include spittle bugs (*Philaenus spumarius*), woolly bear caterpillars (*Isia isabella*), a leaf beetle (*Galerucella nymphaeae*), three aphid species, the blue-green sharpshooter (*Graphocephala atropunctata*), slugs and snails. All of these are generalist species. None of the candidate agents from Asia were found. No root or stem feeders were found. In all cases, damage levels were low.

Extensive exploration for candidate biocontrol agents in Japan has already been carried out by scientists with CABI Biosciences for a biological control program against knotweeds in the United Kingdom. A total of 189 herbivores and 50 fungal pathogens were found on *F. japonica* in Japan. Among the more promising candidate biocontrol agents are a leaf-feeding chrysomelid beetle, *Gallerucida bifasciata*, a sap-sucking psyllid, *Aphalara itadori*, and a leafspot pathogen, *Mycosphaerella* sp. Climate comparisons between regions of Japan and North America suggest that additional exploration in northern areas of Japan may be needed to obtain natural enemies that are suited to climates in North America where knotweeds are most abundant.

FUTURE DIRECTION

To ensure that the candidate biocontrol agents for knotweed will be safe to introduce, they will be tested for their ability to feed and develop on native and economically important plants in North America with an emphasis on plants related to knotweed (family Polygonaceae). A list of test plants has been carefully prepared following guidelines from the Technical Advisory Group on Biological Control of Weeds. The list currently includes 63 species. The testing will be carried out in a USDA-APHIS-certified quarantine facility located at Oregon State University. Additional studies related to this project will be carried out at Cornell University, CABI Biosciences, and Agriculture and Agri-food Canada's Lethbridge Research Center. Host specificity testing will initially focus on those few candidate agents already demonstrated to be host specific in the European program.

Since 1987, weed biocontrol programs in the United States require a rigorous review by the Technical Advisory Group on Biological Control of Weeds (TAG). This panel is composed of members from 15 environmental agencies from the United States plus representatives from Mexico and Canada. The TAG reviews a "petition to import", which includes detailed taxonomies of the agent and target plant, a carefully compiled plant test list, results of host range testing, and discussion of any potential non-target impacts. APHIS-Plant Protection and Quarantine then uses the TAG review and input from individual states to make the final decision to issue the release permit. The TAG review and permit process provide an effective way to ensure that only safe biocontrol agents are introduced.

The final phase of a biological control program is implementation. For the knotweed biocontrol program, releases will be made first into a limited number of locations in both Northeastern and Northwestern states. Initial establishment can sometimes be difficult and so it is important to carefully plan the location and timing of releases. The initial release sites will serve as nursery sites for further collection and redistribution once the populations build up. It typically takes several years for the agents to become abundant at the initial release sites. Although the agent will spread on its own, human aided transport will greatly expedite the process.

Successful weed biocontrol programs begin with localized damage to individual plants and finish with a sustained regional reduction in the plant population. The impacts of biocontrol on the weed population can sometimes be dramatic (>99 percent reduction), but in other cases the level of control is subtle, or variable from site to site. The likelihood of overall success increases with the number of different agent species used. It can take up to a decade or more for the full impact of the biocontrol program to be realized. Quantitative measures of plant population changes over time will be crucial to demonstrating the beneficial effects of this biological control program.

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CYTISUS SCOPARIUS (SCOTCH BROOM) CONTROL USING SEWAGE BIOSOLIDS – PRELIMINARY RESULTS

Jacqueline D. Shaben[1]

ABSTRACT

Cytisus scoparius (L.) Link (Scotch broom) is a quick-growing, leguminous shrub that, since its introduction to western North America, has become very invasive. Its ability to fix nitrogen gives it a competitive edge over other, non-nitrogen-fixing plants when growing in nitrogen-limited soils and, as such, it can form very dense, sunlight-blocking monocultures. Removal of the shrub is possible by cutting, mowing, burning or excavating; however, the prolific seedbank that accumulates under Scotch broom shrubs typically results in a dense re-invasion following shrub removal.

To determine if seedling recruitment can be suppressed by decreasing Scotch broom's competitive advantage over other plants by increasing the nitrogen levels of the soil, I have compared the efficacy of fertilization with sewage biosolids and with ammonium nitrate. Experiments were conducted at three sites in southwestern British Columbia: one on a sandy dredge till site and two on powerline rights-of-way. Site establishment consisted of hand removal of Scotch broom, soil tillage by rototiller and seeding with native grass seed following treatment. Treatments consisted of biosolids, ammonium nitrate and an untreated control. Results from the first two years data of this multi-year study suggest that overall, fewer broom seedlings emerged in the biosolids-treated plots than the other two plot types. If these patterns hold, increasing soil nutrients through fertilization with sewage biosolids could be a useful tool in the control of invasive Scotch broom in non-environmentally sensitive sites.

KEYWORDS: Scotch broom, *Cytisus scoparius*, invasive plant control, sewage biosolids.

INTRODUCTION

Cytisus scoparius (L.) Link (Scotch broom) is a quick-growing, leguminous shrub that is native to southern Europe. Its photosynthetic stems enable it to grow year-round in the moderate climate of west coast North America (Wheeler, et. al, 1979) As such, in this region, Scotch broom can grow quite aggressively in open, coastal meadows such as rare Garry oak (*Quercus garryana* Dougl.) ecosystems as well as open, disturbed sites such as rights-of-way for transmission lines. In ecologically sensitive sites, these dense, sunlight-blocking monocultures effectively suppress native species while broom-invaded disturbed sites act as sources of seed and can significantly increase the dispersal ability of Scotch broom into new ecologically sensitive habitats. It is therefore important to eliminate broom from these human-made sites using broad-scale methods.

Removal of the shrub is possible by cutting, mowing, burning or excavating. In general, however, mechanical removal of broom has proven to be only temporarily successful as a control method because the soil disturbance caused by mowing, cutting and pulling leads to increased germination of a large seed bank which ultimately results in

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the rapid recovery of shrub populations. The goal of this project is to investigate the effectiveness of a soil amendment method for controlling Scotch broom in open, disturbed, non-ecologically sensitive sites.

Scotch broom is from the legume family and is commonly associated with *Rhyzobium* bacteria that fix atmospheric nitrogen for use by the plant. This ability to fix nitrogen allows Scotch broom to establish in soils with low nitrogen content and gives it a competitive advantage over non-nitrogen-fixing plants. However, previous studies have shown legume production is often significantly depressed by nitrogen fertilizer additions (Lauenroth and Dodd 1979, Huenneke et al. 1990). This is likely due to the inhibition of bacterial nodule formation in the presence of increased nitrate (Carroll and Gresshoff 1983). Ongoing suppression of Scotch broom has been demonstrated after fertilization with biosolids (treated sewage sludge) at Discovery Park, a Seattle area ecological restoration site (Deutsch 1997).

Using the aforementioned studies as guidelines for this experiment, I compared the efficacy of two different fertilizer types, ammonium nitrate and treated sewage biosolids, on the suppression of broom seedlings following the mechanical removal of Scotch broom at three field sites in British Columbia.

The underlying hypotheses to be tested are:

1. Whether or not soil fertilization inhibits Scotch broom seedlings.
2. If there is a difference in the effect of two different fertilizers, ammonium nitrate and sewage biosolids, on the suppression of Scotch broom.

METHODS

Sites

The three study sites, Iona Beach, Burnaby Mountain and Duncan, all in British Columbia, have a history of at least 5 years of dense broom that had flowered and produced seed, have little to no slope and are at least 30 m away from any lakes, streams, wells and dwellings and at least 10 m away from any roadways.

The first site, Iona Beach (49°13.01’ N, 123°11.45’ W) is situated at Iona Beach Regional Park, in Richmond, in an area that has no public access. The soil is composed of sand tailings dredged from the Fraser River. The site was covered in a dense stand of Scotch broom, with many shrubs *c.* 15 years and older. Other ground cover consisted of *Bromus tectorum* (L.), mosses and lichens. A slight slope of <2 percent runs east to west. Twenty-one 3.5m x 3.5m plots were established in October 2004 and were blocked along the slope gradient with seven blocks of three plots each. Scotch broom removal occurred in July 2004 by hand-pulling the smaller shrubs and brush-sawing the larger plants, and then carrying all plants off site.

The second site, Burnaby Mountain transmission line right-of-way (49°16.13’ N, 122°53.80’ W), runs along a northeast-to-southwest corridor between dense Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and broad-leaved maple (*Acer macrophyllum*, Pursh) forest. The soil is loamy, > 1m deep and was disturbed in 1999 to install a gas pipeline. The site was covered in a dense stand of even-aged Scotch broom *c.* five years of age that produced flowers and seeds. Other ground cover consisted of Himalayan blackberry (*Rubus discolor* Weihe and Nees) and a few grasses. The site has a very minor slope of <2 percent. In February 2005, entire Scotch broom plants, including roots, were removed by hand. In April 2005, twelve 6m x 2m plots were established and blocked along the slope gradient in 4 blocks of 3 plots.

The third site, Duncan (48°44.02’ N, 123°42.98’W), is also on a transmission line right-of-way. This privately owned property runs along an east-to-west corridor flanked on both sides by Douglas-fir forest. The soil is loamy with broken boulders and has been compacted by heavy machinery. The second generation Scotch broom was dense after having been removed once before by heavy machinery. Other ground cover consisted of mowed grasses and some Oregon grape (*Mahonia nervosa* (Pursh) Nutt.). The site is level. In May 2005, Scotch broom was removed by mowing, soil was loosened with an excavator, roots and large rocks were removed by hand and twelve, 6m x 2m plots were established in four blocks.

Prior to plot establishment, soil samples from all three sites were analyzed for major nutrients (N, P, K, Ca, Mg, Na) and trace elements (As, Cd, Cr, Co, Pb, Hg, Mo, Ni, Se, Zn) to determine background levels prior to treatment with fertilizer.

All plots were rototilled with a hand rototiller to approximately 5 cm, seeded with native shrubs and grass seed then treated with either ammonium nitrate fertilizer at an application rate of 350 kgN/ha applied in 3 installments or biosolids fertilizer at an application rate of 350 kgN/ha applied in 1 installment, plus an untreated control.

Since the biosolids were relatively solid when they were applied and remained in clumps of approximately 2-7cm diameter, they did not spread in an even layer over the soil and covered approximately 50 percent of the soil surface. Breakdown of the clumps occurred primarily via weathering and individual clumps of biosolids were still discernibly intact during monitoring. Most clumps were coated in a layer of soil once they had been rototilled into the soil.

The biosolids that were used in this study were composed of dewatered, pasteurized sewage sludge from the Greater Vancouver Regional District's (GVRD) Annacis Island Wastewater Treatment Plant. The dewatered organic material was recovered from residential (80 percent), industrial (10 percent) and commercial (10 percent) wastewater sources and underwent anaerobic digestion at 55° C for 20 to 30 days resulting in a 99.999 percent pathogen-free, nutrient-rich fertilizer. Biosolids composition is a constant ratio of water, organic matter, soil, nutrients and trace metals.

Yearly average biosolids nutrient composition obtained from the GVRD was used to determine the appropriate bio-solids application rate prior to fertilizing each site. Application rates were determined as per the B.C. Biosolids Best Management Guidelines (McDougall et al. 2001).

Monitoring Scotch broom seedling density

I monitored plant response from June to August of 2005 and 2006. Each plot was divided into four equal-lengthed subplots. A 1m x 1m quadrat was randomly placed within each of the four subplots to census the plants distributed in the subplot in order to determine if Scotch broom seedling emergence and subsequent survival was affected by treatment.

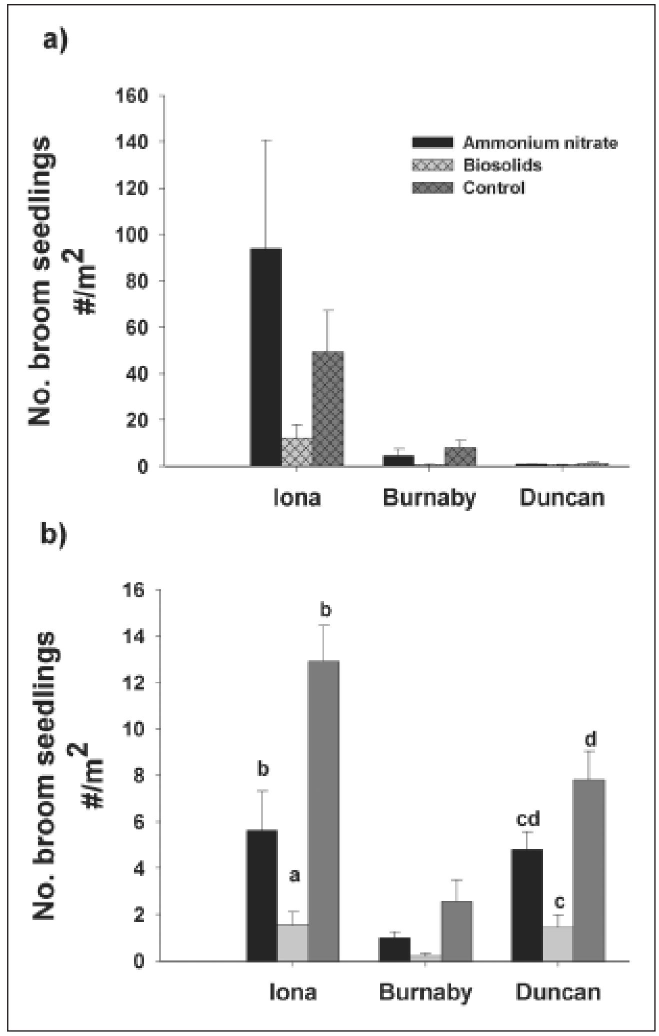

Figure 1—Mean number of Scotch broom seedlings per meter-squared by treatment at all three sites, sampled in (a) July 2005 and (b) July 2006. Error bars represent 1 standard error of the mean.

RESULTS AND DISCUSSION

In both years, the plots treated with biosolids had the lowest Scotch broom seedling density of the three treatments at all three sites (fig. 1).

Other than the 2005 results from Iona Beach, the ammonium nitrate plots consistently displayed the second lowest Scotch broom seedling density, indicating that, although nitrogen addition to the system had an inhibitory effect on the success of broom seedlings, the effect of biosolids, with their full suite of nutrients, was more impressive. In 2005, the Iona Beach site displayed a much greater difference between treatments than was seen at the other two sites. The significantly greater number of Scotch broom seedlings to have germinated at Iona Beach in 2005 is likely a result of the site's having been established in the fall rather than mid-spring like the other two sites, giving the seeds several more months to germinate. Likewise, the increase in broom density seen in the second year of monitoring at Duncan suggests that the seeds had not had the opportunity to germinate in the first growing season (2005), possibly because the site was established so late in the spring. It is also possible that there was simply a larger seedbank at Iona Beach because the site had had Scotch broom for a longer period of time than did the other two sites.

After two years of monitoring the three sites, preliminary results suggest that the application of biosolids at a rate of 350kgN/ha to previously broom-infested areas, has the overall effect of hindering broom seedling survival, with the greatest decrease being at the sandy, Iona Beach site. This site's poor nutrient-holding capacity likely benefitted most from the input of nutrients and organic matter, facilitating the growth of other plant species to compete with the broom (Shaben 2006). It is also possible that some of the broom seeds were simply covered by the biosolids and were therefore hindered from germinating as a physical result of mulching.

CONCLUSION

Scotch broom has become a very problematic invasive plant in many countries around the world, the control of which has been very time consuming and not very effective. Our goal was to test a method that not only would be less time-consuming and therefore less expensive than current methods, but would also use an abundant waste product: sewage biosolids.

The application of biosolids, at the rate of 350kgN/ha, seems like a promising treatment for controlling Scotch broom since the biosolids plots had fewer broom seedlings than the other treatments. This means that, even though Scotch broom suppression was not absolute at any of the three sites, it will nevertheless be easier to control Scotch broom by hand in sites with fewer seedlings.

The results presented here also indicate that the effectiveness of broom suppression using biosolids is site-dependent and it is therefore recommended to conduct fertilization test plots for at least two years prior to treating an entire area.

Finally, as these results represent data that spans only two years of monitoring following treatment and Scotch broom is a long-lived shrub, it remains to be seen whether or not the long-term success of broom suppression can be fully achieved by fertilizing with sewage biosolids.

ACKNOWLEDGMENTS

I would like to gratefully acknowledge the support and guidance of my supervisor, Dr. Judy Myers. I would also like to thank the staff of the Nutrifor program at the Greater Vancouver Regional District and the folks at Sylvis Environmental Consulting for their inspiration and guidance throughout this project. Funding was generously provided by the British Columbia Transmission Corporation, under the direction of Gwen Shrimpton. Site access was made available by Greater Vancouver Regional District Parks, B.C. Hydro, Burnaby Parks and Recreation and the Bjornson family. Much of the fieldwork was made possible with the assistance of Kristen Stevenson. The review of this paper by Dr. Michelle Tseng and Emily Gonzales is very much appreciated. Many thanks go to all the other folks who helped with this project.

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ESTABLISHMENT OF SCOTCH BROOM SEEDLINGS IN DOUGLAS-FIR FORESTS: EFFECTS OF OVERSTORY RETENTION LEVEL AND SEEDBED TYPE

Timothy B. Harrington[1]

ABSTRACT

Establishment of Scotch broom (*Cytisus scoparius* (L.) Link) seedlings was studied for two years after sowing seeds on organic or mineral seedbeds under various overstory retention levels (clearcut, shelterwood, or thinned stands) of 40- to 70-year-old coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var *menziesii*) near Olympia, WA. Herbivory from unknown sources and drought caused reductions in seedling abundance. Seedling abundance from Cohort #1 (sown November 2003) averaged less in clearcuts (0.2 percent of seeds sown) than in shelterwoods (0.9 percent) or thinned stands (2.0 percent). Seedling abundance was greater on organic than on mineral seedbeds in shelterwoods (2.1 versus 0.2 percent) and thinned stands (3.5 versus 1.0 percent), but not in clearcuts (0.1 versus 0.3 percent). Seedling abundance from Cohort #2 (sown November 2004) did not differ significantly among overstory levels or seedbed types and averaged less than 1 percent. Although seedbeds in shelterwoods were slightly moister and warmer than those in thinned stands, these differences in growing conditions did not explain treatment effects on seedling abundance. Scotch broom established successfully under a wide range of overstory retention levels; however, <2 percent of seeds have produced seedlings after two years of observation.

KEYWORDS: Germination, survival, forest understory, soil water, soil temperature.

INTRODUCTION

Scotch broom is a large, non-native, leguminous shrub found extensively throughout 16 eastern and six western U.S. states (USDA NRCS 2006). A native to western Europe, the species was first documented in Washington in 1888 (Parker 2002). Vigorous seedling regeneration enables dense stands to form quickly, increasing hazardous fuels, excluding native plants, and altering community structure of prairies, woodlands, and young forests. Although Scotch broom typically invades roadsides and other disturbed soil areas, it has the potential to grow in conditions of low light availability (Williams 1981), such as those of a forest understory.

In laboratory research, seed germination of Scotch broom peaked at moderate temperatures (18–22°C), and over 65 percent of seeds had an impervious coat with the potential to delay germination for months or even years (Bossard 1993). Seeds remained viable after being stored in glass jars for up to 81 years at the Kew Gardens in England (Turner 1933).

Once germinated, seedlings were able to survive in ten percent of full sunlight, although their biomass was only five percent of those grown in full sunlight (Williams 1981). Scotch broom was not an abundant invader along roads and streams in old-growth forests of Douglas-fir in Oregon (Parendes and Jones 2000). On prairie sites of the

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Puget Sound region in Washington, Scotch broom germinated more abundantly when the cryptogamic layer (biological crust) of glacial outwash soils was intact versus removed (Parker 2002). Vertebrate herbivory decreased biomass of Scotch broom seedlings along the northern coast of California (Bossard and Rejmanek 1994). At a Sierra Nevada foothill site in California, a greater number of seedlings established on disturbed- versus intact-soil microsites; whereas at a coastal site, treatment effects were not significant, in part, because of confounding differences due to seed dispersal by ants (Bossard 1991).

To investigate the potential of Scotch broom to germinate and grow in forest understories, two cohorts of seeds were sown in Douglas-fir stands that had been thinned to several overstory retention levels. In each stand, seeds were sown on both mineral and organic seedbeds to determine if germination substrate affected seedling establishment. Seedling abundance was observed for up to two years after sowing seeds. Several microclimatic variables were measured periodically to potentially explain differences in seedling abundance.

METHODS

Sites and Overstory Treatments

The research was conducted in the Overstory Density Study of Capitol State Forest near Olympia, WA (Harrington 2006). At each of three sites supporting 40- to 70-year old Douglas-fir, plots at least 1.9 ha in area (137 m x 137 m) were randomly assigned various overstory retention levels. Stands were thinned in summer 2000 to leave a relatively uniform spacing of well-formed trees. Advanced conifer regeneration and large hardwoods or shrubs also were cut. Three plots at each site were selected to represent overstory retention levels hereafter designated as clearcuts (absence of overstory trees), shelterwoods (35–54 trees ha^{-1} retained), or thinned stands (84–146 trees ha^{-1} retained). The research was conducted within the outer 30.5-m buffer area of each plot to avoid disturbing ongoing genetic and species-mixture studies underway in the interior of each plot. Although growing conditions probably differed somewhat between the exterior and interior of each plot, the three overstory levels selected per site represented a broad range of light environments.

Cohort #1

In September 2003, Scotch broom seeds were collected from several sites in the Olympia area. Seeds were air dried for 60 days and stored at room temperature in a glass jar. A total of 18 samples of 40 seeds each were counted and placed in separate plastic bags. At each of the three plots per study site, understory shrub and herbaceous species were cleared within a 2- x 2-m area. The upper organic layer of the soil was removed and the soil was mixed to a depth of 30 cm. Approximately 2.5 cm of decomposed litter (O layer) was applied to a randomly located 0.25-m^2 (50 cm x 50 cm) subplot within the cleared area. An adjacent subplot of exposed mineral soil was left uncovered. One sample of seeds was scattered on the surface of each subplot in November 2003. The number of living seedlings in each subplot was counted monthly from April to November 2004, and in April and September 2005 and May 2006.

Cohort #2

In July 2004, seeds were collected from the same locations, air dried, and stored as described previously for Cohort #1. A total of 18 samples of 100 seeds each were placed in separate plastic bags. Within each of the three plots per study site, a new 2- x 2-m area was cleared of all understory shrubs and herbs. In November 2004, the two seedbed types were created and seeds were sown as described for Cohort #1. Seedling abundance of Cohort #2 was determined in April and September 2005 and May 2006. All seedlings from each cohort were removed at the final count to prevent spreading the species.

Microclimate

Overstory cover was measured at randomly selected points throughout each plot in July 2004 with a vertical densitometer (Geographic Resource Solutions, Arcata, CA). Photosynthetically-active radiation (PAR) was measured concurrently with an Accupar® ceptometer (Decagon Devices, Pullman, WA) (see Harrington 2006 for details). Volumetric soil water content at 0-12 cm depth was measured monthly from June to October 2004 and in March, April, and September 2005 with a Hydrosense® (Campbell Scientific, Inc., Logan, UT). Soil water measurements were calibrated to the soils at each site (Harrington 2006) and included readings for each of the organic and mineral seedbeds per subplot. Soil temperature at 2-cm depth was measured with an I-button® sensor (Dallas Semiconductor Corp., Dallas, TX.) placed near the center of each subplot, which logged data every two hours from April 2005 to May 2006.

Statistical Analysis

All statistical analyses were performed with SAS (SAS Institute, Inc. 1999). The experimental design was a randomized complete block with three replications (sites) of six treatments. The six treatments were arranged as a split plot with overstory retention level (clearcut, shelterwood, or thinned stands) as the main-plot treatment and seedbed type (mineral versus organic) as the split-plot treatment. Periodic values of seedling abundance by subplot were expressed as proportions of the total number of seed sown and the data were normalized with an arc-sine, square-root transformation (Sokal and Rohlf 1981). The same transformation was applied to normalize measurements of soil water content. Mean, minimum, and maximum daily values of soil temperature were averaged by month. Data for seedling abundance, soil water, and soil temperature were subjected to a repeated-measures analysis of variance (ANOVA) in SAS Procedure MIXED to determine the significance ($\alpha = 0.05$) of overstory level, seedbed type, and their interaction, while accounting for random effects of individual subplots. The analysis of seedling abundance was conducted separately for each cohort on the pooled spring (April or May) and fall (September) measurements from the study to provide a relatively even spacing in time among measurements (i.e., an assumption of repeated-measures analysis). The same approach was used for analysis of soil water and temperature data. Analyses were conducted with maximum likelihood estimation assuming an autoregressive covariance structure to account for time series trends. For each ANOVA, residuals were plotted against predicted values of the dependent variable to verify that residual variances were relatively homogeneous. If an interaction was detected among experimental factors, pairwise comparisons of least-squares adjusted means were conducted with Bonferroni adjusted probabilities (Sokal and Rohlf 1981). The following orthogonal contrasts were performed to partition effects of overstory level (contrasts (1) and (2)) and its interaction with seedbed type (contrasts (3) and (4)):

(1) Absence versus presence of overstory trees (clearcuts versus the mean of shelterwoods and thinned stands).
(2) Shelterwoods versus thinned stands.
(3) Effects of seedbed type differ between absence and presence of overstory trees.
(4) Effects of seedbed type differ between shelterwood and thinned stands.

RESULTS

Herbivory from unknown sources appeared to be the primary cause of reductions in seedling abundance over time, especially in shelterwoods and thinned stands where leaves of seedlings were commonly browsed in the late summer and fall, resulting in their subsequent mortality. Drought may have been responsible for mortality of some seedlings, particularly in thinned stands where wilted seedlings were observed in late summer. Seedling height after one growing season ranged from 5 to 20 cm except for one seedling that attained a height of 60 cm in a clearcut plot.

Average abundance of Scotch broom seedlings in Cohort #1 was less in clearcuts than in shelterwoods and thinned stands (orthogonal contrast (1): $P = 0.016$) (fig. 1). None of the treatment-by-timing interactions were significant ($P \geq 0.163$). Organic seedbeds had higher seedling abundance than mineral seedbeds in Cohort #1, but only in shelterwoods and thinned stands (orthogonal contrast (3): $P = 0.048$) (fig. 2). Seedling abundance from Cohort #2 never exceeded 1 percent. Although the interaction of overstory level and timing was significant for Cohort #2 ($P = 0.023$), pairwise comparisons between overstory levels within each timing failed to detect significant differences in seedling abundance.

Average overstory cover was 0, 31, and 62 percent in clearcuts, shelterwoods, and thinned stands, respectively,

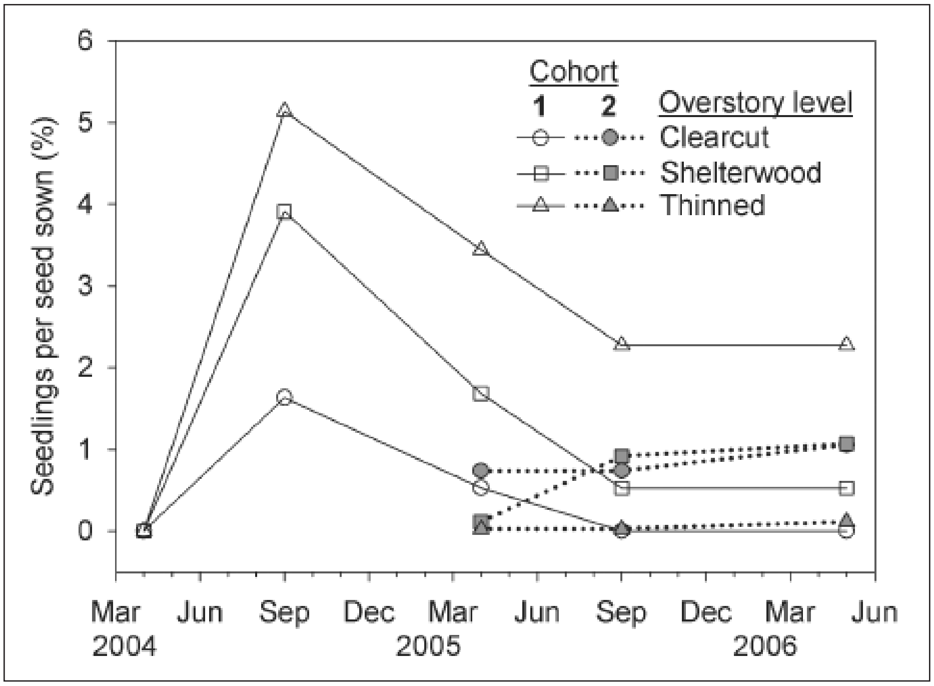

Figure 1—Average abundance of two cohorts of Scotch broom seedlings during two growing seasons after sowing seeds in various overstory retention levels of Douglas-fir. Cohort #1 was sown in November 2003 (standard error = 0.657) and cohort #2 was sown in November 2004 (standard error = 0.302).

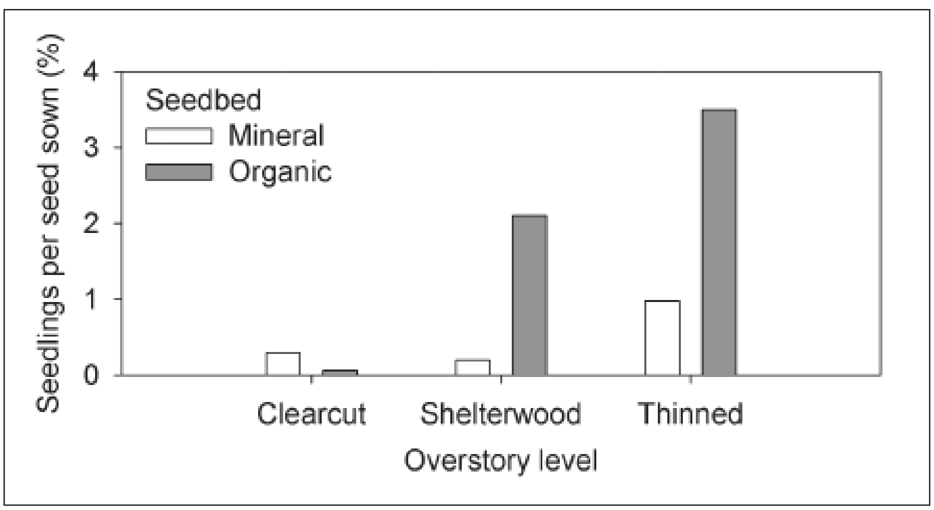

Figure 2—Average abundance of Scotch broom seedlings from Cohort #1 as affected by the interaction of Douglas-fir overstory retention level and seedbed type (standard error = 0.602).

and average PAR was 100, 62, and 34 percent of full sunlight, respectively (Harrington 2006). Average soil water content was greater in shelterwoods than in thinned stands (orthogonal contrast (2): $P = 0.023$) (fig. 3a). Soil water content did not differ significantly ($P = 0.358$) between organic and mineral seedbeds, and none of the treatment-by-timing interactions was significant ($P \geq 0.095$). Mean daily soil temperature was 1.5°C greater in shelterwoods

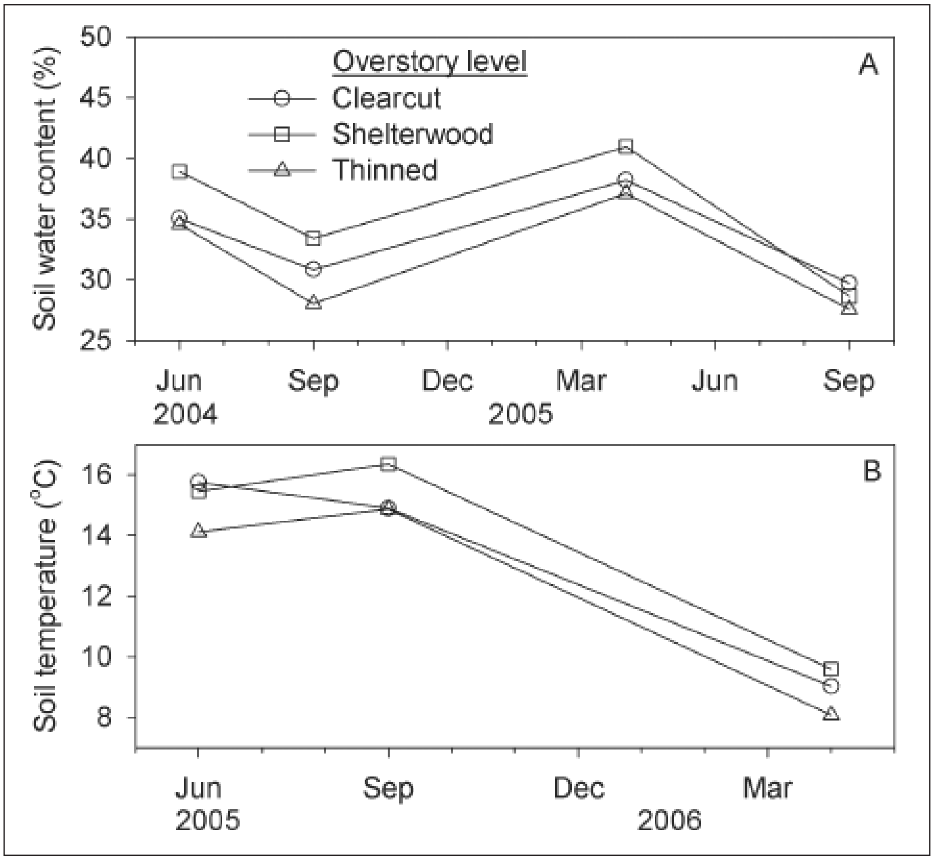

Figure 3—Effects of Douglas-fir overstory retention level on average (a) soil water content (standard error = 0.872) and (b) mean daily soil temperature (standard error = 0.307) during 2004–2006.

than in thinned stands (orthogonal contrast (2): $P = 0.028$) (fig. 3b). Average values of soil water and mean daily soil temperature in clearcuts were intermediate to those in shelterwoods and thinned stands. Minimum daily soil temperature in September 2005 was lower in clearcuts (7.8°C) than in shelterwoods (9.9°C) or thinned stands (9.9°C) (data not shown). Maximum daily soil temperature did not vary significantly with overstory level or its interaction with timing ($P \geq 0.244$).

DISCUSSION AND CONCLUSIONS

Abundance of Scotch broom seedlings in Cohort #1 increased with level of overstory retention in Douglas-fir stands, and it was greater on organic than on mineral seedbeds. Only 1 percent or fewer of the seeds sown in Cohort #2 produced a seedling, and seedling abundance failed to differ among treatments. Although seedbeds in shelterwoods were slightly moister and warmer than those in thinned stands, these differences in growing conditions did not explain treatment effects on seedling abundance. The combined effects of overstory shade and an organic seedbed probably created "safe" sites that facilitated germination of Scotch broom. For example, shade from overstory trees reduced evaporative demand in the understory, and organic seedbeds may have had greater variation in microtopography and improved moisture-holding characteristics than mineral seedbeds. Once germinated, however, the seedlings became susceptible to predation and drought.

The current status and ultimate fate of un-germinated seeds from the two cohorts remain unknown. Although greater visibility of seeds in clearcuts or on mineral seedbeds may have contributed to increased predation

(Bossard 1991), viable seeds of Scotch broom probably remain on the experimental seedbeds because of their potential for delayed germination. Bossard (1990) estimated that, from a given cohort of seeds, 98 percent would be viable, 5 percent would be lost to seed predation by insects, 40 percent would germinate in the current year, 25 percent would germinate in the second year, and the remaining 28 percent would germinate in future years.

Results of this study suggest that moderate levels of overstory retention provide more favorable conditions for germination and short-term survival of Scotch broom seedlings than clearcuts, possibly through drought amelioration. However, up to two years after sowing two separate cohorts of seeds, ≤2 percent have produced seedlings. Thus, it is likely that some seeds remain and may yet germinate. This uncertainty regarding continued viability of the sown seeds makes it difficult to predict which environment is most suitable for germination and survival of Scotch broom. Continue monitoring of the experiment will be required to address this longer-term question.

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BIOLOGY AND MANAGEMENT OF INVASIVE HAWKWEEDS (*HIERACIUM* SPP.) IN THE PACIFIC NORTHWEST

Linda M. Wilson[1]

ABSTRACT

In the western United States and Canada, there are about fourteen species of non-native hawkweeds (*Hieracium* spp.) belonging to two subgenera. Hawkweeds are fibrous-rooted, perennial herbs growing from a stout rhizome. Collectively, they possess many characteristics that allow a species to become invasive: perennial life cycle, apomictic reproduction (seed production without pollen), high seed production and germinability, broad ecological amplitude, long distance seed dispersal, regeneration from root fragments, root buds, rhizomes and stolons, rapid generation time (ca. 63 days), and broad latitudinal range. In addition, several hawkweed species, particularly *H. aurantiacum*, orange hawkweed, are popular ornamental species, further increasing spread. Invasive hawkweeds infest a range of habitats in the Pacific Northwest, predominantly occurring in open fields, mountain meadows, clearings in forest zones, permanent pastures, and other modified habitats where the soil is well drained, coarse-textured, and moderately low in organic matter. Management of hawkweed-invaded sites has relied mostly on selective herbicides, which are effective in suppressing hawkweeds but reinvasion occurs unless other plant species fill the gaps left by hawkweed removal. Hawkweeds are thought to persist in these sites because they capture nitrogen in nutrient-poor soils, thus limiting nutrients available to competing plants. Fertilizers and soil fertility management have been used to effectively control hawkweeds in some areas, especially in new hawkweed infestations or where hawkweed density is relatively low. Long-term management of hawkweed needs to emphasize altering conditions in the plant community to favor grasses and desirable forbs following initial control efforts. Alternative control solutions, including biological control, are being investigated.

KEYWORDS: Hawkweed, *Hieracium*, invasive plant, weed ecology.

INTRODUCTION

Invasive hawkweeds (*Hieracium* spp.) comprise a complex of about 14 species occurring throughout the Pacific Northwest (PNW). The name *Hieracium* comes from the Greek 'hierax,' meaning hawk; allegedly keen-sighted hawks of yore ate the sap of the brightly colored plants to sharpen their eyesight. Rapid spread of hawkweeds and distribution across many habitats has been possible because much of the land in British Columbia, coastal and north-eastern Washington, northern Idaho, and northwestern Montana is considered susceptible to invasion by these aggressive weeds.

TAXONOMY

Hawkweeds are in the tribe Lactuceae of the family Asteraceae, having all strap-shaped (ligulate) flowers and a milky latex in stems and leaves. The genus *Hieracium* is divided into three subgenera. Subgenus *Chionoracium* (formerly subgenus *Stenotheca*) represents the ± 20 native species in North America. In the PNW, subgenus *Hieracium*,

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Table 1—Invasive, non-native hawkweed species in western North America[a]

Scientific name Subgenus Pilosella	Common name	Distribution
Hieracium caespitosum Dumort. (= *H. pratense* Tausch.)	meadow hawkweed	AB, BC; ID, MT, OR, WA, WY
Hieracium aurantiacum L.	orange hawkweed	AB, BC; AK, ID, MT, OR, WA, WY
Hieracium pilosella L.	mouse ear hawkweed	BC; OR, WA
Hieracium flagellare Willd.	whiplash hawkweed	BC; WY
Hieracium floribundum Wimm. & Grab.	kingdevil hawkweed	BC; ID, MT, OR, WA
Hieracium praealtum Vill. (= *H. bauhini* Schult.)	queendevil hawkweed	BC
Hieracium piloselloides Vill.	tall hawkweed	BC; MT
Hieracium glomeratum Froel.	yellowdevil hawkweed	BC; ID, WA
Subgenus *Hieracium*		
Hieracium laevigatum Willd.	smooth hawkweed	BC; WA
Hieracium lachenalii Gmel. (= *H. vulgatum* Fries.)	common hawkweed	BC; ID, WA
Hieracium sabaudum L.	European hawkweed	BC; WA
Hieracium atratum Fries.	polar hawkweed	WA
Hieracium maculatum Sm.	spotted hawkweed	BC; WA
Hieracium murorum L.	wall hawkweed	BC; AK

[a] Including Alaska, Alberta, British Columbia, Idaho, Montana, Oregon, Washington, and Wyoming

which includes both North American and European components, comprises two native species and six species from central and eastern Europe, including smooth hawkweed, common hawkweed, European hawkweed, polar hawkweed, spotted hawkweed, and wall hawkweed (table 1).

Subgenus *Pilosella*, entirely European in origin, represents most of the invasive species in the PNW. The eight known invasive species in subgenus Pilosella include meadow hawkweed, orange hawkweed, mouse-ear hawkweed, whiplash hawkweed, kingdevil hawkweed, queendevil hawkweed, and tall hawkweed (table 1). A new species, yellowdevil hawkweed, was identified from southeastern British Columbia in 2001. This was the first report of this species in North America (Wilson et al. 2006). A recent molecular phylogeny of *Hieracium* in North America indicates a clear separation between subgenera as well as separation between native and invasive species (Gaskin and Wilson, in press). Preliminary molecular studies on the genetic diversity of orange hawkweed has revealed a single clonal line common to all populations examined to date (Lila Fishman, pers. comm.).

DESCRIPTION OF INVASIVE HAWKWEEDS

Hawkweeds are fibrous-rooted, perennial herbs growing from a stout rhizome. Plants reproduce by seeds and vegetatively by stolons, rhizomes, and adventitious root buds. The small, dandelion-like heads are borne singly at the top of a long, hairy to hairless stem, or in compact, rounded or loose, elongated panicle-like clusters. All but one invasive species have yellow flowers (likewise, all but one native species have yellow flowers). Seed production is primarily asexual through apomixis (the production of seeds without pollen), although occasional sexual reproduction, involving outcrossing and hybridization, is believed to occur. Hawkweeds are distinguished largely on a few key morphological characters, including leaf, stem and phyllary (involucral bract) pubescence. Hairs, both type and abundance, are important characters used to distinguish hawkweed species. Three types of hairs are common: long simple hairs; dark, glandular hairs; and small, star-shaped (stellate) hairs. All invasive hawkweeds are polyploid (n=9) and typically asexual, in contrast to native species which are entirely diploid and sexual.

Invasive hawkweeds commonly occur as populations of intermediate types throughout the PNW, making identification of invasive hawkweed species difficult. Abundant variation in plant characteristics due to apomixis and perhaps occasional hybridization, environmental and site influences, and natural variation (polymorphism) has resulted in the description of thousands of species, subspecies and types worldwide. Identification of invasive and native hawkweeds can be difficult. To aid land managers in identification of invasive hawkweeds, a diagnostic key was developed (Wilson 2006).

INVASION SUCCESS

Hawkweeds invasive in the Pacific Northwest and Intermountain West are pre-adapted to many coastal and inland habitats that are climatically similar to those in their native European ranges. Hawkweeds possess many characteristics that allow a species to become invasive: perennial life cycle, apomictic reproduction, high seed production and germinability, broad ecological amplitude, long distance seed dispersal, regeneration from root fragments, root buds, rhizomes and stolons, rapid generation time (ca. 63 days), and broad latitudinal range. In addition, several hawkweed species, particularly orange hawkweed, are popular ornamentals. They have been and continue to be spread by intentional and accidental human activities.

Invasive hawkweeds infest similar habitats in Washington, Idaho, Oregon, Montana and British Columbia. Found predominantly in open fields, mountain meadows and clearings in forest zones, hawkweeds also infest permanent pastures, timber harvest units, abandoned farmland and other modified habitats where the soil is well drained, coarse-textured, and moderately low in organic matter (Wilson et al. 1997).

Throughout most of the PNW, hawkweeds generally grow at elevations ranging from 725 m (2400 feet) to over 1700 m (5600 feet). They occur more commonly at lower elevations above 51°N latitude. None of the invasive hawkweeds are found in the natural grasslands or shrub-steppe of the PNW, nor are they invasive in the dry habitats of south-central British Columbia and central Washington.

MANAGEMENT

Management of hawkweed-invaded sites has had mixed results. Controlling hawkweed has relied mostly on selective herbicides. Herbicides are effective in suppressing hawkweeds but reinvasion occurs unless other plant species fill the gaps left by hawkweed removal. Control and management of meadow hawkweed has been complicated by the plant's ability to persist following chemical and cultural control inputs.

Herbicides have been widely used to manage hawkweeds. An experiment was established in 2005 near Santa, Idaho, to evaluate control of meadow hawkweed (*H. caespitosum*) after foliar applications of aminopyralid, clopyralid, and triclopyr in each of three seasons: spring (bolting stage), summer (flowering stage), and fall (senescence) (Wilson et al. 2006). Each treatment varied by the percent mortality of meadow hawkweed rosettes, and prevented seed production one and two months after treatment. The greatest amount of control was achieved using aminopyralid at 7 oz / acre applied at the rosette stage.

Hawkweeds are thought to persist in nutrient-poor soils because they capture limited nutrients, possible through their association with soil mycorrhizal fungi. Fertilizers and soil fertility management have been used to effectively control hawkweeds in some areas, especially new hawkweed infestations or where hawkweed density is relatively low.

The Invasive Hawkweed Consortium comprises numerous stakeholder groups with interest in the biology, ecology, and management of invasive hawkweeds. Members include the Idaho Department of Agriculture, Idaho Department of Lands, University of Idaho, Hawkweed Action Committee, Rimrock Hawkweed Cooperative, USDI Bureau of Land Management, British Columbia Ministry of Forests and Range, British Columbia Ministry of Agriculture and Lands, Washington State Noxious Weed Control Board, Montana Noxious Weed Trust Fund, Kootenai County Weed Control Board, Stevens County Weed Control Board, USDA Forest Service, Pend Oreille County Weed Board, Palouse Cooperative Weed Management Area, Selkirk Cooperative Weed Management Area, Panhandle Lakes Cooperative Weed Management Area, Dow AgroSciences, Nez Perce BioControl Center, Potlatch Corporation, and Crown Pacific. The goals of the Invasive Hawkweed Consortium are primarily to develop a classical biological control program, but also to increase awareness through workshops, field tours, and extension outreach activities. In addition to biological control, the Consortium supports research in invasive hawkweed genetics, and herbicide and fertilizer field studies. Although biological control of invasive hawkweed is not currently available, investigations are underway to determine if several insect species from hawkweed's native range in Europe are suitable agents (Grosskopf 2005).

CONCLUSION

The occurrence of several species of invasive hawkweeds in the Pacific Northwest poses additional challenges to managers. Managers will need to be able to distinguish non-native, invasive hawkweeds from the native hawkweed that occur in the region before they can develop and implement effective management programs. Established infestations of hawkweeds are fast spreading and successful control will require aggressive suppression or containment programs, including early detection and eradication programs. Regardless of the control method used for initial removal of hawkweed, long-term management of hawkweeds must emphasize altering conditions in the plant community to favor the establishment of desirable vegetation.

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FUNGAL ENDOPHYTES IN SPOTTED KNAPWEED: DO THEY AFFECT ITS INVASIVENESS?

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ABSTRACT

To what extent do biotic interactions affect plant competition and fitness? This question relates to the general problem of understanding invasions by some exotic plants. Without the benefit of any evolutionary period that would allow for local adaptation to environmental conditions, some exotic plants are able to enter a plant community and outcompete the natives. The Novel Weapons Hypothesis, developed by Ray Callaway and his colleagues, explains this phenomenon in terms of biotic, plant-to-plant interactions that favor the novel invader. Developed from earlier ideas about allelopathy, the hypothesis appears to explain the phenomenal success of spotted knapweed, *Centaurea stoebe*, in western North America. Spotted knapweed roots have been reported to exude a chemical, (-)-catechin, that is thought to be a novel weapon suppressing the growth of naïve neighbors in the native plant community. Questions were raised last year, however, by a report of an unsuccessful attempt to repeat some of the research on (-)-catechin. Our interest in spotted knapweed as a model system for plant invasions is also based on biotic interactions. But, in our case, we are hypothesizing that fungal endophytes are influencing plant competition, as well as other plant behaviors. There is precedent, at least by analogy, for this hypothesis. John Klironomos showed that soil microbiota may promote plant invasions because invasive species avoid or fail to elicit negative feedback with soil pathogens. This negative feedback reduces the competitiveness and abundance of many native plants. More specifically, knapweed's interactions with native plants are affected by soil fungi, and soil microbes in its native range inhibit knapweed, as predicted by Klironomos.

KEYWORDS: *Centaurea stoebe*, spotted knapweed, endophytes, competition.

ROLE OF ENDOPHYTES

Soil microbes are notoriously diverse (Curtis et al. 2002, Fierer and Jackson 2006); some may be 'residents,' whereas others may be 'transients' that disappear from the soil community as their specific plant substrate degrades. It is not yet clear whether fungal endophytes of aerial plant parts are generally soil residents or transients; the latter seems more likely. Apart from a brief soil phase, even non-systemic endophytes would thus spend most of their poorly understood life cycle in their host plants. In any event, endophytes are associated with a growing list of ecological roles: thermotolerance of plants growing in geothermal soils (Redman et al. 2002); community biodiversity (Clay and Holah 1999); enhancement of plant growth (Ernst et al. 2003). Specific endophytes may play specific roles, and many plants host very diverse arrays of endophytes (Ganley et al. 2004; Ganley and Newcombe 2006).

Endophytes in introduced plants like knapweeds must either have been co-introduced in seeds of their host, or have 'jumped' from other plants in the invaded range of

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their host. Because we are interested in the nativity or origin of fungi, we have been sampling fungal endophytes from knapweed in both its native range in Europe, and in its invaded range in North America. From 2004 to 2006, we have obtained isolation frequencies from seeds of the native range in Europe varying from 13 to 100 percent; some sites in the Pacific Northwestern portion of the invaded range have yielded relatively high isolation frequencies also, but more often samples of 100, surface-sterilized seeds have yielded no endophytes at all. The reasons for the variation in isolation frequency may emerge in analyses that we will be performing with our in-progress, extensive, 2006 survey.

So far, most of our endophytes from knapweed seed have tended to belong to a few fungal genera: *Alternaria, Fusarium*, and *Botrytis*. There are also rarer occurrences of endophytes belonging to *Ulocladium*, *Cladosporium*, *Aureobasidium*, *Epicoccum*, *Phoma*, and *Nemania*. Within many of these genera, we are also discovering diversity in ITS haplotypes; for *Alternaria*, various Alt a1 haplotypes are emerging. Some haplotypes have been found in knapweed in both of its ranges, and these are suggestive of co-introduction. Differences in community composition between native and invaded ranges also appear likely, and these differences may affect behavior, including invasiveness.

IDENTIFYING SOURCE AND MOVEMENT OF ENDOPHYTES

Greenhouse experiments have been performed with seedlings that were either E^+ [endophyte-infected] or E^- [endophyte-free]. Flowers of both E^+ and E^- plants, after pollination with bee abdomens, yielded E^- seed. Apparently, endophytes are not systemic in spotted knapweed. An endophyte cannot be vertically transmitted in seed of a knapweed plant unless it has infected that plant at some point. In the greenhouse, infection events are unlikely as foliage is never wet for the period of time that most fungi require for infection.

Re-isolation experiments in the greenhouse have revealed that if flowers are pollinated and then inoculated 48 hours later, the inoculated endophyte can be re-isolated from the surface-sterilized, mature seed at a rate that varies with the endophyte. In other words, infection can take place during flowering, but it is likely that it can also occur before flowering.

Some endophytes produced sesquiterpenoid volatiles; these same isolates repelled seedhead weevils, *Larinus minutus*, when inoculated into pollinated flowers 12 hours prior to weevil introduction. Many knapweed endophytes significantly reduced germination of seed of Idaho fescue, *Festuca idahoensis*. Significantly fewer knapweed endophytes reduced germination of seed of knapweed itself. One *Fusarium* isolate caused significant knapweed seedling mortality.

In model competition experiments that were patterned after Callaway's groundbreaking work (Ridenour and Callaway 2001), endophytes in knapweed affected Idaho fescue plants grown in the same pots. E^+ knapweed plants were significantly bigger (i.e., greater dry biomass) than their E^- counterparts. The opposite was true of fescue: E^+ plants were significantly smaller than the E^-. This result, in particular, is difficult to reconcile with the emerging differences in isolation frequency in the two ranges. Where spotted knapweed is native and non-invasive, endophytes occur at high frequency. Where spotted knapweed is non-native and invasive, endophytes are frequently absent. Resolution of this conundrum will likely involve distinctions among specific endophytes, their distributions, isolations from leaves and roots in addition to seeds, and possibly other factors.

In conclusion, our experimental research to date suggests that endophytes influence the invasiveness of spotted knapweed by affecting competition and relationships with herbivorous insects. But endophyte diversity in spotted knapweed is substantial, and effects on competition and other biotic relationships may very well depend on specific endophytes. Our understanding of the distributions and life cycles of specific endophytes in knapweed's native and invaded ranges is still fragmentary. Explaining invasiveness in simple terms has proven challenging for ecologists (Blair et al. 2006), but no hypothesis to date has included the contributions of endophytes.

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SUCCESSFUL BIOLOGICAL CONTROL OF INVASIVE PLANT SPECIES IN WASHINGTON

Jennifer Andreas[1], Tara J. Zimmerman[2], Daniel L. Fagerlie[3],
Brad W. Gaolach[2], Dale K. Whaley[4], and Tyler W. Wilson[3]

ABSTRACT

The Integrated Weed Control Project (IWCP) of Washington State University Extension has been implementing biocontrol of weeds since 1999. In this time we have noted several substantial successes after the biocontrol releases. *Larinus minutus* Gyllenhal (Coleoptera: Curculionidae), a seed-feeding beetle, has reduced *Centaurea diffusa* Lam. (diffuse knapweed) by not only reducing the seed production, but outbreak populations of the adults have defoliated and killed many plants. Before- and after-treatment pictures demonstrate reduced populations within five years. Similarly, *Lythrum salicaria* L. (purple loosestrife) has been dramatically reduced with the use of the foliage-feeding beetles, *Galerucella calmariensis* (L.) and G. *pusilla* (Duft.) (Coleoptera: Chrysomelidae). Infestations throughout much of Washington have been reduced to non-damaging levels in as little as four years after the initial release. Recently, *Mecinus janthinus* Germar. (Coleoptera: Curculionidae), a stem-mining beetle for the control of *Linaria dalmatica* (L.) Mill. (Dalmatian toadflax), is demonstrating similar results in areas of eastern Washington. Although successes such as these are encouraging, many challenges still exist. The distribution of biocontrol agents for a variety of weed species and their impact in reducing invasive plant populations are critical to weed management success. IWCP aims to meet these challenges by continuing biocontrol redistribution, site-specific evaluation and planning, and insect and plant monitoring. IWCP serves county, state, federal, tribal and private land-managers by providing expertise, on-site evaluations, educational seminars and demonstrations, and biological control agents at no cost.

Project Objectives

- Educate land-managers on rapid response for new invaders and integrated weed control methods.
- Encourage and increase biological control agent use for large and scattered infestations.
- Support innovative methods in weed control.
- Improve coordination of weed boards, USDA Forest Service Ranger Districts, Native American Tribes and other land-management agencies and land owners in Washington and surrounding states.

Ongoing Work and Future Plans

- Continue implementing biocontrol across the state.
- Continue educating land-managers about biocontrol.

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- Monitor biocontrol agents and weed infestations to assess the efficacy of the practice.
- Further expand early detection / rapid response efforts.
- Continue developing educational pamphlets and workshops.
- Continue pesticide recertification courses.
- Encourage and assist land-managers with appropriate pasture management techniques and revegetation information.
- Provide expertise and on-site evaluations and recommendations to land-managers.
- Act as a resource to land-managers for weed control information and equipment (e.g., weed wrenches).

KEYWORDS: Integrated weed control, biological control, early detection-rapid response, IWCP.

GARDEN LOOSESTRIFE (*LYSIMACHIA VULGARIS*), A SPREADING THREAT IN WESTERN WATERWAYS

Katie Sauter Messick[1] and Drew Kerr[2]

ABSTRACT

Garden loosestrife (*Lysimachia vulgaris*) is a rhizomatous perennial native to Eurasia that is widely distributed across the northern United States and southern Canada. It thrives in wetland and riparian areas. Considered naturalized in areas like New England, it may be that the cold winters are the only factor keeping it from becoming invasive. Garden loosestrife is particularly worrisome for several reasons. It is difficult to control, and according to Cusick (1986), it will form easily overlooked thickets of non-flowering young plants before appearing in flower as a fully established infestation. Also, although several western states have mild climates that are conducive to serious infestations of garden loosestrife, only Washington State has it listed as a noxious weed. In King County, Washington, there are a number of large garden loosestrife populations that may give us some indication of its real potential for spread in the West and the challenges in controlling it. The King County Noxious Weed Control Program is currently working with government agencies, community groups and private landowners to control garden loosestrife. Our control strategies vary according to the extent of the infestation and land ownership in each area.

KEYWORDS: Garden loosestrife, *Lysimachia vulgaris*, King County, wetlands.

HOW TO RECOGNIZE GARDEN LOOSESTRIFE

Garden loosestrife is a tall, emergent perennial in the primrose family with a large terminal panicle of showy, bright yellow flowers in July and August (fig. 1). The leaves are ovate and softly hairy, generally in whorls of three or four, and are usually dotted with small orange or black glands. The stems are also hairy, and in a large stand five percent or more can be fasciated (i.e., flattened). In King County, we have noted the red rhizomes reaching more than ten feet into adjacent waters.

Garden loosestrife is extremely aggressive and forms monocultures, much like its common namesake, purple loosestrife (*Lythrum salicaria*). In fact, it outcompetes purple loosestrife, as well as aggressive natives like spirea (*Spirea douglasii*) and cattails (*Typha latifolia*). The result is a depauperate shoreline plant community, clogged waterways and diminished wildlife habitat.

WHERE TO FIND GARDEN LOOSESTRIFE

The first records of garden loosestrife in King County are from Juanita Bay on Lake Washington in 1978. By 1990, it had spread along shorelines throughout the Lake Washington and Sammamish systems. Populations in Lake Burien, to the south of Seattle, and in Rutherford Slough near Fall City in the Snoqualmie River basin were discovered in the late 1990s, possibly originating from garden plantings. Most recently, this program has found pioneering stands dotting the banks of the Snoqualmie River downstream (north) of Rutherford Slough (fig. 2).

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Figure 1—Garden loosestrife along the Sammamish River.

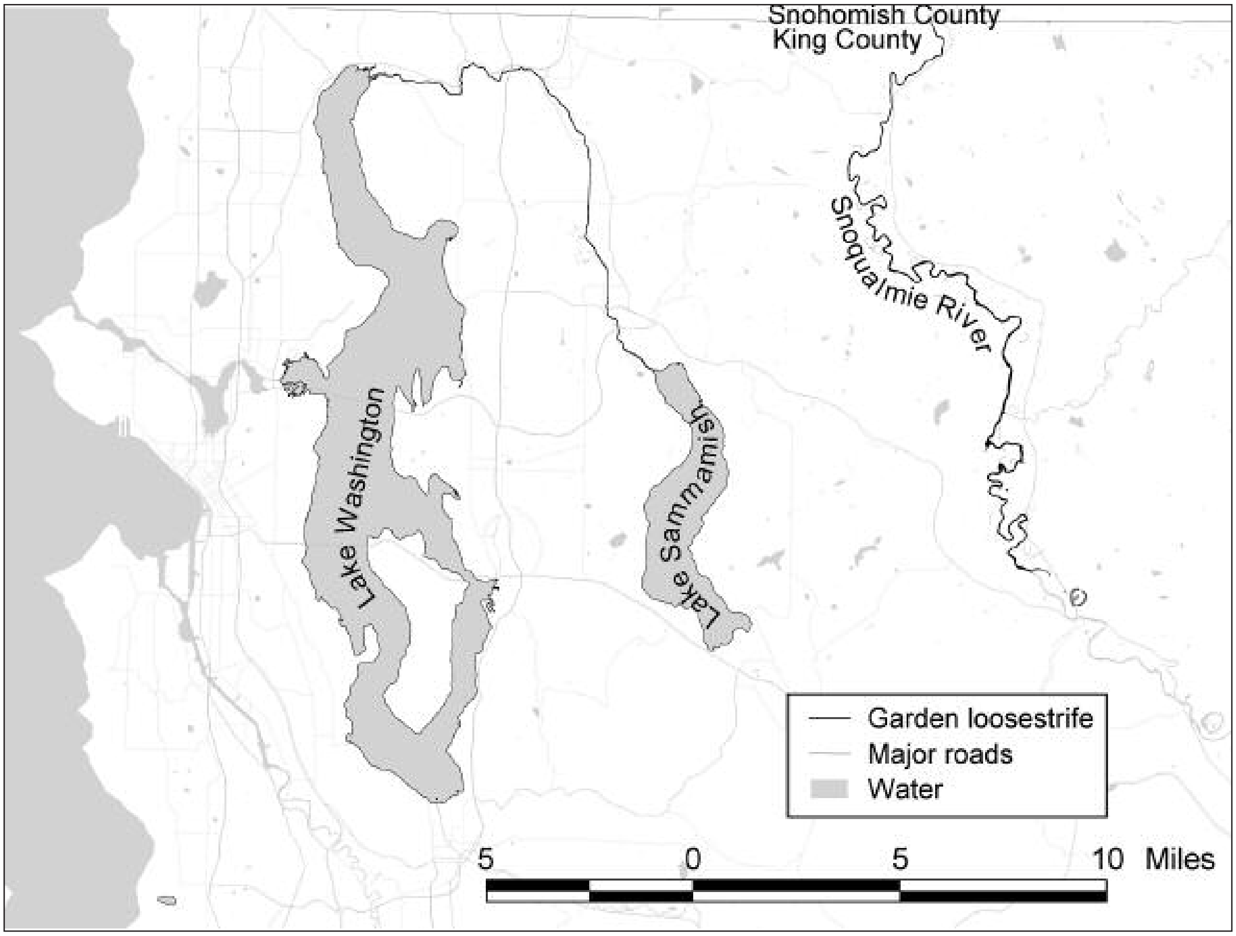

Figure 2—Garden loosestrife distribution in King County.

CASE STUDY: CONTROL AROUND LAKE SAMMAMISH

An estimated 25 percent of the Lake Sammamish shoreline is infested with garden loosestrife, covering some 20 total miles. The worst hit spots are natural areas, most particularly the large public parks at the north and south ends of the lake. While the public agencies are dealing with the extensive, inaccessible populations in those areas, King County's strategy with private landowners on Lake Sammamish has been one of voluntary control. In 2006 we sent 1,000 letters to property owners informing them of the situation and asking them to control the plants on their land, and five percent responded to the letter. Using continued direct mailings, workshops and other forms of public education, we hope to increase the percent of property owners voluntarily controlling the garden loosestrife as we gain control of the plant on public land.

CASE STUDY: CONTROL IN RUTHERFORD SLOUGH

The discovery of garden loosestrife in Rutherford Slough presented a different problem, since this was the only area in a large and highly functional river basin to be infested. Our program worked with the property owners to hire contractors to apply herbicides to the populations starting in 2002 (fig. 3a). The most effective herbicide tried has been a 1.5 percent solution of triclopyr TEA (Renovate3™), which has significantly reduced the population over much of the Slough as of 2006 (fig. 3b). A two percent solution of

Figure 3—Garden loosestrife infestation on Rutherford Slough (a) before (2002) and (b) four years after herbicide treatment (2006).

glyphosate (e.g. AquaMaster™ or Rodeo™) is also effective, but the reduction in all plants can lead to greater germination of the seed bank. Unfortun-ately, in 2004 garden loosestrife was found in the mainstem Snoqualmie River, and we are now forming a strategy to contain the further spread of this weed.

NEXT STEPS

1. Continue to survey all known areas of infestation to get a solid picture of the garden loosestrife population in King County.
2. Work with homeowners in the large lake systems to get voluntary control.
3. Work toward eradication of garden loosestrife in the Snoqualmie River basin.
4. Apply principles of "early detection, rapid response" to any new infestations.
5. GET THE WORD OUT: HAVE YOU SEEN THIS WEED?

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GARLIC MUSTARD CONTROL: IS SUCCESS A POSSIBILITY? STRATEGY AND POTENTIAL IMPACT

Karen J. Peterson[1]

ABSTRACT

Garlic mustard, *Alliaria petiolata* (M. Bieb.) Cavara and Grande, is an extremely invasive biennial plant that is poised to significantly impact the Pacific Northwest's biodiversity unless urgent action is taken to curtail it. Garlic mustard has demonstrated the ability to thrive in sensitive forested ecosystems. An aggressive IPM approach is recommended which should include a combination of methods, most importantly, monitoring and timely control to prevent seeding. It is imperative that all property stakeholders allocate a portion of their time and resources each year for garlic mustard control and monitoring. The state of Washington has the unique advantage of having it listed as a Class A noxious weed which mandates eradication as a landowner responsibility. Garlic mustard populations in King County are still limited enough that there is a chance that its spread can be restricted in the short term and that they could be eventually eradicated. The majority of known sites have been prevented from seeding in the last few years and, as a result, spread has been contained. A coordinated regional approach will be necessary to achieve long-term eradication of garlic mustard in the Pacific Northwest.

KEYWORDS: Noxious weeds, garlic mustard, invasive plants, Pacific Northwest, Washington.

INTRODUCTION

Garlic mustard has already caused widespread environmental damage on the East Coast and the Midwest (Welk et al. 2002). Garlic mustard's extreme adaptability makes it highly likely to become a similar problem on the West Coast. It produces significant amounts of seed (up to 500 seeds per plant) which are moderately long lived in the soil (up to 10 years). It rapidly colonizes exposed, disturbed sites, but will also invade relatively undisturbed forested sites, displacing native vegetation (Nuzzo 1999). When cut back, it will often continue to re-sprout and flower. It has recently been shown that garlic mustard produces a toxin that interferes with the ability of trees to take in necessary nutrients (Stinson et al. 2006).

Recent modeling (Welk et al. 2002) shows the existing and potential distribution of garlic mustard in North America (figs. 1a-b). The extensive potential distribution of garlic mustard, combined with the significant degree of potential impact suggests garlic mustard presents a major threat to the biodiversity of forested ecosystems in the Pacific Northwest.

Garlic Mustard Control in King County

Garlic mustard was first discovered in King County in 1999. At this stage, the infestations were likely in a lag phase of establishment. The area of garlic mustard found has increased since that time, although the area controlled has also increased (fig. 2). The increased infestation area can be attributed to a combination of improved and more thorough survey techniques and to actual spread of garlic mustard beyond the original range. Most of these new sites are small, consisting of private properties. From 2004 to

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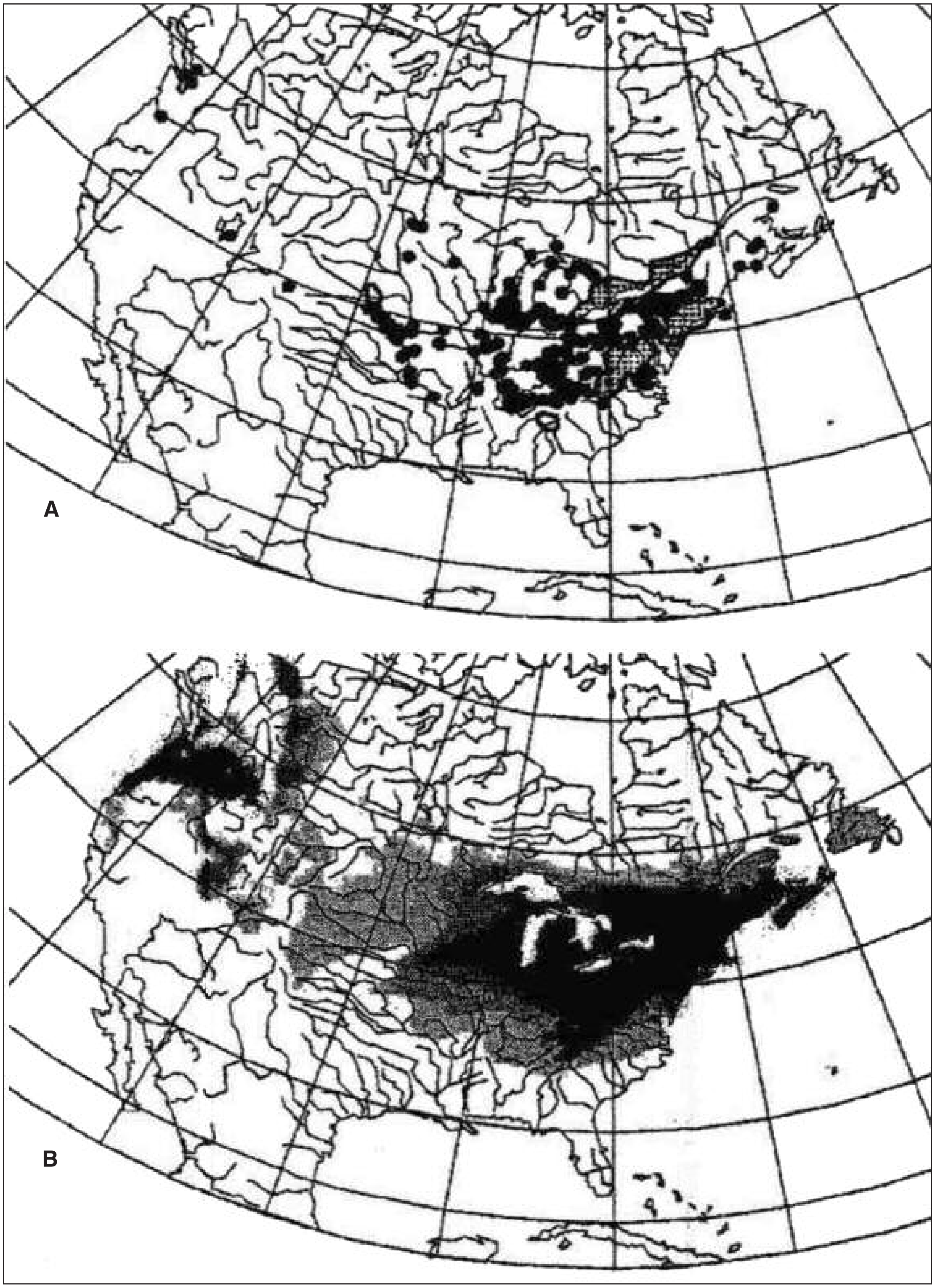

Figure 1—Populations of garlic mustard in North America in (a) 2002 and (b) potential future populations of garlic mustard in North America if not controlled (Welk et al. 2002).

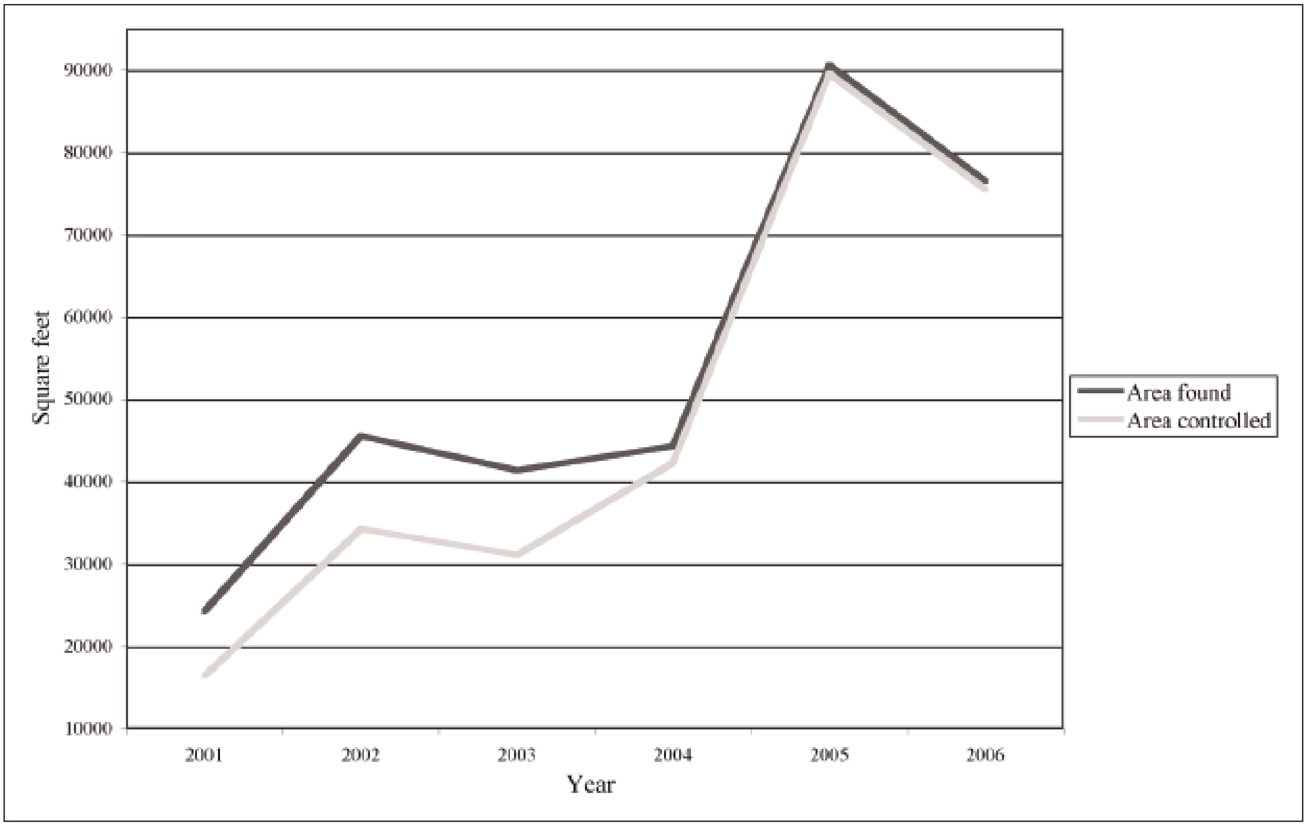

Figure 2—Area of garlic mustard found and controlled from 2001 to 2006 in King County, WA.

2006, close to 100 percent of known garlic mustard infestations have been controlled and seeding prevented. The exceptions may be in some forested urban parks, where it is possible that a small number of plants have escaped detection in the undergrowth.

A comprehensive survey and control regimen has been implemented that involves large numbers of volunteers and parks gardeners searching for and pulling out flowering garlic mustard. Significant support and resources have been provided by the Seattle Parks Department who are responsible for a number of large infestations. In known infestation sites, this approach is successfully achieving reduced garlic mustard density, an elimination of seeding, and recruitment of native plants. It is becoming more difficult to find new large patches of garlic mustard.

Successful eradication of garlic mustard requires increased education of the public. This should engage their support in the following ways: 1) reporting new infestations, 2) working to control them, and 3) monitoring results. Eradication of garlic mustard is a landowner responsibility under the Washington State Noxious Weed Control Law. Enforcement action against landowners who fail to cooperate in the control of garlic mustard on their land will also be implemented now that a clear community standard of control has been established.

An important part of the long-term control strategy will involve cooperation and coordination with other federal, state and local agencies fighting this problem in the Pacific Northwest. There are several known garlic mustard sites in the Western states. Sharing information and developing an overarching regional strategic approach to control will be essential for long-term success.

CONCLUSION

With comprehensive, aggressive control and collaboration with other local, state and federal agencies as well as private citizens, we do have the chance to reduce and eventually eradicate garlic mustard in the Pacific Northwest. This will avoid potentially significant environmental impacts to the region.

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THE ECOLOGICAL CONSEQUENCES OF GIANT KNOTWEED INVASION INTO RIPARIAN FORESTS

Lauren Urgenson[1] and Sarah H. Reichard[2]

ABSTRACT

Giant (*Polygonum sachalinense*), Japanese (*P. cuspidatum*), and bohemian (*P.* × *bohemicum*) knotweeds are non-native plant invaders of riparian corridors throughout the United States and Europe. Knotweed invasion is suspected to alter critical riparian processes including forest and understory regeneration, streambank stability, soil nutrient cycling and allochthonous litter inputs. Currently, there is limited quantitative evidence of the level or significance of these impacts. We investigated the effects of giant knotweed invasion on: 1) the composition and diversity of forest understory communities, and 2) the quantity and nutrient quality of riparian leaf litter inputs into streams. Field data were collected in summer and fall 2004 at Grandy Creek, a tributary of the Skagit River, Washington, densely colonized by giant knotweed.

There was a negative correlation between giant knotweed invasion and the species richness and abundance of native understory herbs, shrubs, and juvenile trees. In addition to the displacement of native vegetation, data suggest that knotweed invasion alters stream nutrient subsidies from riparian litterfall. We observed an average 70 percent reduction of leaf litter from native species in knotweed invaded sites. The carbon-to-nitrogen ratio (C:N) of senesced knotweed leaves was 52:1, a value 38 to 58 percent higher than dominant native riparian species. Analysis of nutrient re-absorbance from senescing leaves revealed that knotweed reabsorbed 75.5 percent of its foliar nitrogen prior to litterfall. In contrast, native species reabsorbed 4.8 to 33 percent.

Knotweed's displacement of understory herbs, shrubs and juvenile trees can have detrimental and long-lasting effects on riparian forest structure and function. Loss of juvenile trees in the understory leads to a decline in overstory tree density and canopy cover over time and can alter the successional trajectory of riparian forests. Deciduous and coniferous trees are foundation species within Pacific Northwest riparian forests. Empirical evidence from the region demonstrates that loss of riparian trees has detrimental effects on the bank stability, hydrology, nutrient loading, micro-habitat conditions and aquatic biota of adjacent lotic systems.

Litterfall from riparian vegetation comprises a primary source of nutrients and energy in forested streams and backwater channels. High C:N, as in knotweed litter, is generally associated with low resource quality and slower rates of nutrient release through decomposition. Thus, knotweed leaf litter may provide a poorer quality food resource for aquatic consumers than native riparian species. Efficient autumnal re-absorbance of foliar nitrogen suggests that knotweed transports a majority of nitrogen resources down into its own rhizome system for reuse during subsequent growing seasons. In contrast, native species contribute a higher percent of their nutrient resources to riparian soils and aquatic environments through their leaf litter.

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By displacing native vegetation and altering the species composition and nutrient quality of riparian litterfall, knotweed invasion may have a detrimental impact on the structure and productivity of riparian forests and adjacent aquatic food webs.

KEYWORDS: Giant knotweed, *Polygonum sachalinense*, *Polygonum cuspidatum*, *Polygonum* × *bohemicum*, invasion impacts, riparian vegetation.

MANAGEMENT APPROACHES

Orange hawkweed (*Hieracium aurantiacum*) (Lisa K. Scott)

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STRATEGIC MANAGEMENT OF PUBLIC INVASIVE SPECIES PROGRAMS

Steven J. A. Burke[1]

ABSTRACT

Government invasive species control programs can create significant public value in terms of economic, environmental, recreational and public health benefits. These benefits are however constrained by: 1) inconsistencies between jurisdictions, and 2) lack of effective administration within many jurisdictions. As well as being ecological opportunists, invasive species also can be viewed as exploiting administrative and jurisdictional weaknesses and opportunities. Increasingly, land management agencies are developing strategies to focus their activities to achieve defined invasive species program missions and goals. Effectiveness of these strategies will be increased through their alignment with overarching regional and national strategic frameworks to achieve a more collaborative, coordinated and accountable effort. Equally important, although less strongly emphasized, strategic management is necessary over time to successfully implement these strategies, and account for increases in public value. In King County, Washington, strategic management is used to deliver increased public value from noxious weed control. Working towards the mission of "minimizing noxious weed impact on the environment, recreation, public health and economic resources," the program measures performance using indicators for specific operational goals. These goals and some 2005 performance indicator results are: 1) eradicating existing infestations and preventing new infestations of Class A (highest priority) noxious weeds - 60 percent of area found to date eradicated, and 2) controlling designated Class B (second-tier priority) noxious weeds to below thresholds of significant impact - 78 percent of area found in 2005 controlled. A variety of management tools are used to improve these indicators over time. These emphasize alignment of staff accountability with program goals, and increasing their empowerment and participation in program decision-making. Strategic management of public-sector invasive species programs is critical to enhancing their effectiveness. By better aligning the strategies of the various government entities engaged in invasive species management and more effectively implementing them, the public value created by these public programs can be significantly increased.

KEYWORDS: Invasive species, noxious weeds, management, government, public.

WHY PUBLIC INVESTMENT?

Government action is essential for effective management of many invasive species. Landowners acting in their own self-interest will not always efficiently reduce the costs and impacts created by invasive species introduction and spread. This is a classic case of market failure where insufficient action by some landowners, jurisdictions and communities can result in massive externalized costs to others (Perrings et al. 2005).

Minimizing the impact of invasive species to the economy, public health and the environment is clearly a public good (McNeely 2004). Public programs therefore play an important role in a comprehensive and effective approach to managing them. These programs can create significant

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public value and are justified when that value greatly exceeds their costs to citizens.

WEAKNESSES OF THE CURRENT PUBLIC-SECTOR EFFORT

Unfortunately, the lack of effective administration of government invasive species control programs in the United States currently constrains the public value they can produce. It also provides fodder for those who desire less government involvement in invasive species management.

In particular, benefits from the management of invasive species are being significantly constrained by: 1) inconsistencies between jurisdictions, and 2) lack of effective administration within many jurisdictions. As well as being ecological opportunists, invasive species also can be viewed as exploiting administrative and jurisdictional weaknesses and opportunities.

There has been significant recent effort to address these challenges. Increasingly, land management agencies and organizations are developing invasive species strategies. These identify their goals, objectives, activities and measures of success for their programs.

Some examples (in decreasing scale and increasing level of detail) include:

- Global Strategy for Addressing the Problem of Alien Invasive species (IUCN Global Invasive Species Programme)
- National Invasive Species Management Plan (National Invasive Species Council)
- Pulling Together Strategy – FICMNEW National Strategy for Invasive Plant Management
- USDA Forest Service National Strategy and Implementation Plan
- Washington Invasive Species Council – proposed strategy
- Oregon Invasive Species Action Plan
- Idaho Strategic Plan for Managing Noxious Weeds
- Washington State Noxious Weed Management Plan
- King County Noxious Weed Control Program – Strategic Plan

Nonetheless the current overall national invasive species management effort is still unfocused and poorly coordinated, despite significant strategic planning effort and considerable funding (in excess of one billion dollars annually) by the Federal Government (GAO 2005). A recent survey of a range of federal, state and local agency staff involved in weed management found that they believed lack of consistent and adequate funding was a significant barrier to improved invasive species management outcomes (GAO 2005). It is clear, however, that lack of coherent and accountable national strategy is a more fundamental problem.

Making progress in reducing the impacts of invasive species will require two critical improvements in the development and implementation of these strategies: 1) strategic alignment and 2) improved strategy implementation.

STRATEGIC ALIGNMENT

Strategic alignment of invasive species programs can be defined as increasing the effectiveness of invasive species strategies through their alignment with overarching regional and national strategic frameworks to achieve a more collaborative, coordinated and accountable effort.

Invasive species do not respect jurisdictional boundaries or authorities. Poorly coordinated actions from individual jurisdictions will be far less effective than harmonized approaches and they possibly will be doomed to failure in the long run (Doelle 2003). More importantly, poor invasive species management in just one jurisdiction can be the weak link which undermines the effectiveness of others. The prevention and control of invasive species is a weakest-link public good (Perrings et al. 2002) where the ability to provide public good is in the hands of the least supportive and cooperative jurisdictions and stakeholders.

Increasing comprehensiveness is a major challenge to invasive species management in the United States. American natural resource managers must deal with highly fragmented jurisdictions which in no way correspond to the natural systems managed. While every state has some form of invasive species legislation, their scope and implementation vary widely.

Successful invasive plant management strategies must therefore be comprehensive and engage or compel even the most unenthusiastic stakeholders. Currently there is no comprehensive approach at the national level and in many states. Some examples of the weakest jurisdictional links are: 1) in Washington State, Douglas County does not have a noxious weed board or program, and 2) nationally, the State of Mississippi also does not have an effectively operating state noxious weed law.

Another major challenge that needs to be overcome is how to achieve a degree of consistency regarding the objectives and methods between agencies that operate in bureaucratic silos. A land management agency that simply concerns itself with the control of invasive species on its lands in isolation, without regard to neighboring landowners and pathways of spread, would be a classic example of this.

The effectiveness of invasive species management strategies will increase with their comprehensiveness and level of adoption of application and the level of scale (temporal and spatial) as described in Figure 1.

One promising approach is to develop and encourage networks based on shared strategy that achieve collaboration and accountability across bureaucratic boundaries. Increased cooperation and coordination is essential for the long-term effective management of invasive species (GAO 2005). At the regional, national and international level, these collaborative institutional frameworks can address gaps, weaknesses and inconsistencies of bureaucratic silos (Doelle 2003, Behn 2006).

A lot of work has already been done developing overarching strategic frameworks at the international and national level. These, however, tend to be symbolic documents of good intent rather than effective operational strategies. They primarily give lip-service recognition to the need for broader coordination but offer little accountability to the overarching objectives. These frameworks must be reinforced by a hierarchy of accountability mechanisms and made more comprehensive in order to work.

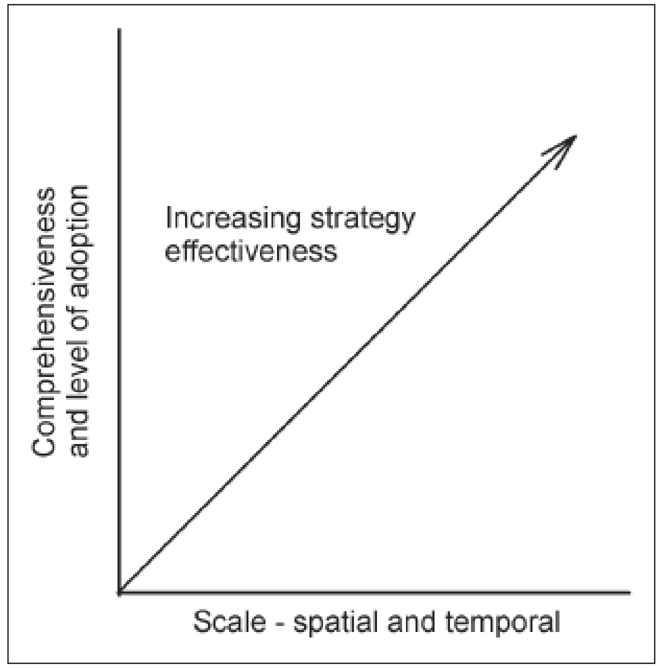

Figure 1—The relationship of strategy comprehensiveness, level of adoption and scale to its effectiveness.

Existing multi-jurisdictional strategies such as the National Invasive Species Management Plan involve few or no binding performance management or accountability mechanisms to drive the achievement of the overarching objectives. An accountability hierarchy must be established to support these strategic frameworks, encourage collaboration and establish performance management mechanisms. For example, the excellent Forest Service Invasive Species Strategy would be more effective if it were strongly imbedded in an accountable national approach.

One way to achieve such accountability would be to link funding to participation in overarching strategies. This could be done by: 1) providing dedicated new funding or incentives to participating jurisdictions or organizations based on performance, or 2) making commitment to overarching strategies binding in some way, perhaps by requiring participation and accountability as a pre-requisite to eligibility for certain state or federal funds.

Some elements of linking federal funding to performance are a feature of the currently unappropriated Noxious Weed Control and Eradication Act (2004). This funding

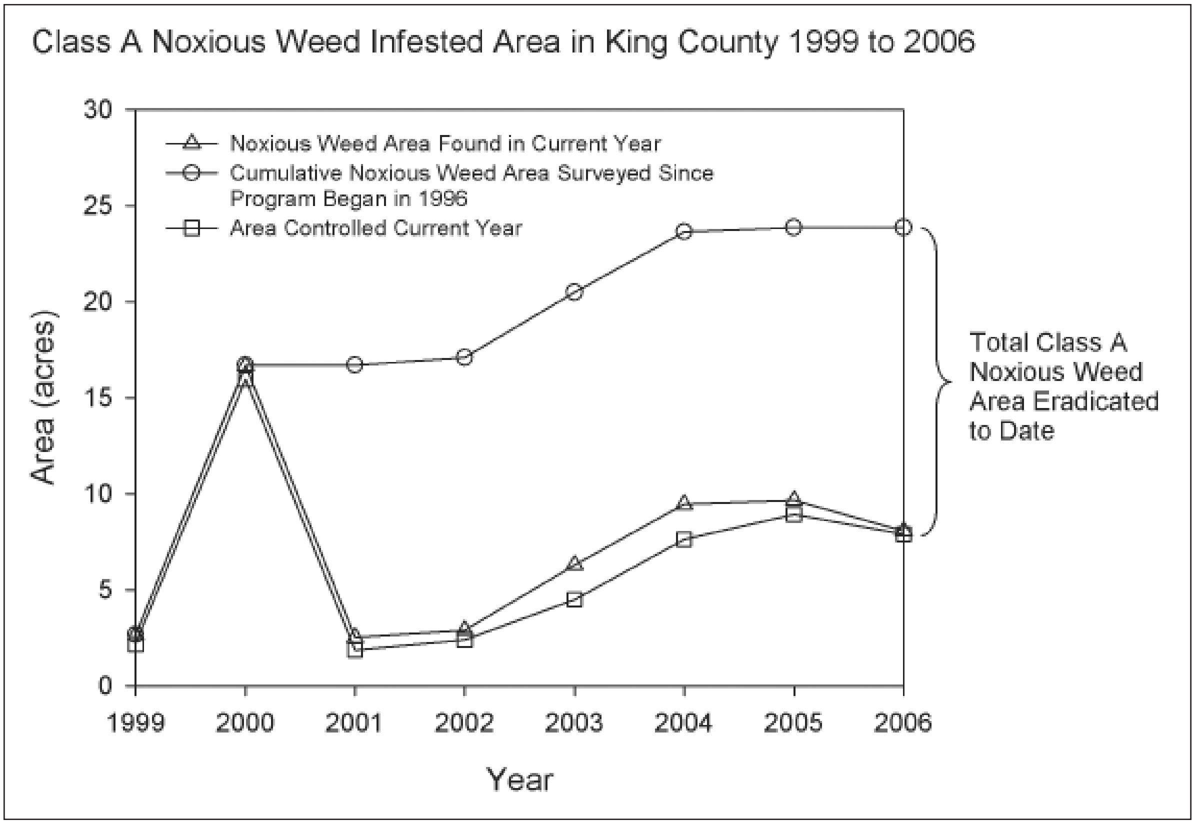

Figure 2—Control and eradication of Class A noxious weeds in King County 1999 – 2006.

would be tied to grants and agreements to weed management entities working in a collaborative fashion.

Another way to drive increased collaboration and accountability is to identify a peak agency responsible for this. A National Center for Invasive Species Management has been proposed (ESA 2006). This would expand the role of the National Invasive Species Council to facilitate policy coordination and implementation of the National Invasive Species Management Plan. The National Invasive Species Management Plan is a good strategic framework that would be made far more effective if its stakeholders were accountable to a lead agency linked to federal funding initiatives.

Finally, Cooperative Weed Management Areas (CWMAs) can also play a valuable role in increasing larger-scale collaboration and comprehensiveness of invasive plant control. The growth and vitality of the CWMA concept is very encouraging.

IMPROVED STRATEGY IMPLEMENTATION

Improved strategy implementation is employing strategic management over time to successfully implement programs and account for increases in public value.

Strategic management "helps organizations define their visions and core purposes – the outcome goals that are most important to them and aim their entire systems at fulfilling them. This is accomplished by changing the organization's purpose, accountability incentives, power structure and culture" (Osborne and Plastrik 2000).

Strategic management processes are well described and understood. They include defining missions, goals, outcomes and outputs; devising strategies to achieve them; engaging and motivating stakeholders; defining performance measures; negotiating performance agreements with implementing organizations; and monitoring and evaluating results. Incentives are created to improve performance and drive the organization towards its goal.

For example, in King County, Washington, strategic management is being used to deliver increased public value from noxious weed control. Here, a comprehensive approach to noxious weed management is being implemented across the county. This includes coordinating and working with 38 separate incorporated cities, at least four state and two federal land management agencies, two tribes as well as, of course, the 1.8 million citizens of the county (U.S. Census Bureau 2005).

Working towards the mission of "minimizing the impact of noxious weeds on the environment, recreation, public health and economic resources of King County," the program measures performance using indicators for specific operational goals. These goals and 2005 results for some relevant performance indicators are:

a) Eradication of existing infestations and preventing new infestations of Class A (highest priority) noxious weeds – 60 percent of noxious weed area found to date eradicated (fig. 2).

b) Controlling designated Class B (widespread and 2^{nd} tier priority) noxious weeds to below thresholds of significant impact - 78 percent of designated Class B infestations found in 2005 controlled.

Some strategic management tools the program is employing to drive improvement of these indicators over time are:

- Clearly developed mission goals and performance measures
- Aligning individual accountability with program goals
- Team review of individual activities and outputs
- Identifying and developing team culture and values
- Contracting out a significant proportion of operational tasks to lower cost providers
- Staff empowerment and participation in program decision-making

CONCLUSION

Invasive species management is a significant public administration challenge. Invasive species spread by effectively exploiting ecological opportunities, and administrative and jurisdictional weakness. There is considerable potential to provide significantly increased public value from investment in invasive species control programs. Large scale, comprehensive, collaborative strategies and subsequent strategic management are necessary for their long-term success.

ACKNOWLEDGMENTS

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INVASIVE PLANT MANAGEMENT FOLLOWING THE 2003 OKANAGAN VALLEY WILDFIRES, BRITISH COLUMBIA

Lisa K. Scott[1]

ABSTRACT

The South Okanagan-Similkameen Invasive Plant Society (SOSIPS) identified a need to invest substantial efforts on weed management (inventory, treatment, monitoring and research) within the region of three wildfires that occurred in the South Okanagan in 2003. The three wildfires – Okanagan Mountain Fires, Vaseux and Anarchist (Osoyoos) – encompassed an estimated 34,500 hectares of shrub-steppe and forested landscapes. Wildfire and associated soil disturbances create an ideal seedbed for invasive plant establishment; consequently, effective management is an even greater concern in fire-impacted areas. There is also limited published data on the predicted fire response of invasive plants occurring in the Southern Interior, although most species are anticipated to rapidly spread as a consequence of the fire and related soil disturbances. A five-year study focusing on the impact of the wildfire and associated soil disturbances on the invasive species was initiated in 2004 for each of the fire-impacted sites. A 'task team' of collaborating stakeholders was established for each site, including representatives from regional, provincial and federal governments, industry, conservation groups, ranchers and private landowners. The task teams cooperatively developed and implemented an effective approach to invasive plant management. Detailed inventories were completed, treatment was conducted (herbicide, physical, biological and cultural control), permanent vegetation plots and photo points were established and predictive models were developed for selected species. The risk assessment models will help guide future management in the Okanagan and potentially can be expanded to other areas of the Southern Interior.

KEYWORDS: Wildfire, invasive plant management, inventory, monitoring, treatment, risk assessment model.

INTRODUCTION

The summer of 2003 was an unprecedented year for wild fires in British Columbia (BC). Abnormally hot, dry weather resulted in over 2,500 wildfire starts, most of which occurred in the BC Interior. The fires also set an all-time record high for the number of urban-wildland interface fires. In the Okanagan alone, over 334 homes and many businesses were lost. Total costs for the year were estimated at $700 million (Canadian dollars).

The Okanagan Valley was impacted by three wildfires – Okanagan Mountain, Vaseux and Anarchist (Osoyoos). The Okanagan Mountain fire was the largest of the three, consuming 30,000 hectares of ponderosa pine parkland, Douglas-fir forest, Engelmann spruce and other forested habitats. The South Okanagan-Similkameen Invasive Plant Society had already identified this site as a priority treatment area in 2000, primarily due to the extensive infestation of the provincially noxious weed, tansy ragwort (*Senecio jacobaea*). The Vaseux fire area was also previously identified as a priority area for the South Okanagan Region. This fire encompassed 3300 hectares of antelope-brush shrub-steppe, a provincially endangered ecosystem,

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ponderosa pine parkland and Douglas-fir forest. These habitats have been invaded by sulphur cinquefoil (*Potentilla recta*), a regionally noxious weed. The Anarchist wildfire was the smallest of the three wildfires, consuming 1200 hectares of sagebrush shrub-steppe, ponderosa pine parkland and Douglas-fir forest. Prior to the fire, the area was not identified as a priority site for invasive plant management.

Following the wildfires, the necessity for effective weed management (inventory, treatment, monitoring and research) within the confines of these three wildfires was more critical. Invasive plants thrive in fire-impacted sites. Wildfires release soil nutrients, expose ground surfaces, reduce shade and stimulate seed germination (through breakage of dormancy). These factors assist the regeneration of both native plants and invasive species. Unfortunately, due to their competitive advantages, invasive species are often the first to colonize fire-impacted sites. Once established, invasive species are hard to control, extremely competitive and quick to spread. As a result, the ability of native and desirable plants to re-establish is limited.

Fire-impacted areas are further prone to the establishment of invasive plants through post-fire soil disturbances. Creation of fireguards (or firebreaks), salvage logging, mushroom picking and off-road recreation all help to expose soils and spread invasive plant fragments and seeds. Consequently, effective management of invasive plants is an even greater concern in fire-impacted areas. As a result, the South Okanagan-Similkameen Invasive Plant Society identified the three Okanagan fire-impacted sites as a top priority for invasive plant management.

PROJECT COORDINATION

In early 2004, a ‘task team’ of collaborating stakeholders was established for each of the three wildfire sites. Each team included representatives from regional, provincial and federal governments; industry; conservation groups; ranchers; and private landowners. The task teams met biannually, including field trips, and cooperatively developed and implemented an effective approach to invasive plant management for each of the wildfire locations. This coordinated effort increased the effectiveness of results and allowed for the most efficient use of limited funding through joint funding proposals.

INTEGRATED MANAGEMENT

Inventory and Mapping

Inventories were conducted using a Trimble® Pro XRS Differential GPS with a TSC-1 data logger in accordance with the Ministry of Forests Invasive Alien Plant Program Standards. Invasive plant infestations were logged as point features with an associated distribution code. Areas of exposed soils resulting from fire suppression activities and high burn severity were also mapped due to their vulnerability to weed invasion. Post processing occurred in Arc View v3.2a to create geographical ‘shape files’ containing polygons identifying plant species and distribution code.

Comprehensive inventory and mapping of invasive plants within the three project areas was essential to improving the efficiency of management as well as establishing a base-line inventory for monitoring and evaluation.

The following invasive plants were focal species detected within the three fire-impacted project areas:

- Tansy ragwort (*Senecio jacobaea*)[a]
- Orange hawkweed (*Hieracium aurantiacum*)[a]
- Sulphur cinquefoil (*Potentilla recta*)
- Diffuse knapweed (*Centaurea diffusa*)
- St. John’s-wort (*Hypericum perforatum*)
- Canada thistle (*Cirsium arvense*)
- Bull thistle (*Cirsium vulgare*)
- Hound’s-tongue (*Cynoglossum officinale*)
- Oxeye daisy (*Chrysanthemum leucanthemum*)[a]
- Dalmatian toadflax (*Linaria genistifolia* spp. *dalmatica*)
- Plumeless x nodding thistle hybrid (*Carduus* sp.)[a]
- Nodding thistle (*Carduus nutans*)[b]
- Common burdock (*Arctium minus*)

[a] Okanagan Mountain Inventory only
[b] Anarchist Mountain Project Inventory only

Treatment

The inventory and mapping component of the project was used to generate planning maps that guided invasive plant management activities. Treatment activities included an integrated approach, involving seeding of native grasses, herbicide spot-treatment, hand cutting, and release of biological control agents. Select areas of all three project sites were seeded with an agronomic seed mixture developed from input by each task team. Seeding was used as a preventative tool to help establish a competitive ground cover to reduce weed establishment. Certified spray contractors conducted all herbicide treatments. Chemical control focused on areas of seed pick up and dispersal for target weed species. Additional physical control was conducted by the BC Conservation Corps contracted through The Nature Trust of BC for tansy ragwort at the Okanagan Mountain site. Biological control agent releases were conducted by SOSIPS with insects provided by the BC Ministry of Forests and Range or the BC Ministry of Agriculture and Lands.

Monitoring and Research

General observations made during field assessments showed a positive response to treatments within each of the fire sites. General observations of seeding indicated a high germination rate of most agronomic species. Visual inspections of herbicide treated areas showed a high level of control (90-95 percent) for all sites.

In 2004, vegetation plots (Daubenmire plots - 20 x 50 cm) and photo points were established at each of the fire sites. Plot transects were selected in areas that support various noxious weeds or where weeds were detected on the periphery of the transect. Each plot was surveyed for percent cover and abundance for each plant species present. Subsequent data from these plots will be recorded at least once during the five-year term of the project, and ideally at ten years post-fire.

The weed inventory data from 2004 was also used in the development of predictive (spatial) models for tansy ragwort and sulphur cinquefoil. Variables used to develop the models included crown closure, forest type (dominant timber type), fire intensity mapping (completed by the BC Ministry of Environment) and elevation. The result of the modeling process was the production of risk assessment models for each species. The models have since been applied to the remaining Okanagan landscape and have assisted in guiding management of invasive species.

Education and Outreach

Field days, workshops and community stewardship events were essential to overall success of the projects. Of particular value was the landowner contact conducted in the Anarchist Fire area, as the fire directly affected an estimated thirty private landowners. Two educational field days were conducted for private landowners living on Anarchist Mountain. The events featured an invasive plant presentation, focusing on weed species abundant in the community.

At Okanagan Mountain, a full day field tour of the fire-impacted landscape was held exactly two-years post-fire. Participants toured three high profile locations, chosen to highlight site concerns, containment priorities, treatment successes and seeding response. This event served to increase the awareness of tansy ragwort and other invasive plants, provide an example of successful multi-stakeholder coordination and highlight treatment efforts.

FUTURE OUTLOOK

The South Okanagan-Similkameen Invasive Plant Society will continue to work closely with partners to achieve on-going collaboration for invasive plant management. Each of the three project areas remains a high priority for SOSIPS and the task team partners. Continued invasive plant management over the next three years is essential to protect the natural resources within these areas as well as the significant investments of 2004-2006, and years prior. A monitoring and evaluation regime will be continued to determine the efficiency of treatment and adjust management practices as required. Education/outreach/stewardship programs with landowners/managers, tenure holders and recreations group will also continue. SOSIPS will endeavor to work with as many of these sectors as possible, to raise awareness of invasive plants and garner additional support. Additional research opportunities and partnerships will be investigated.

ACKNOWLEDGMENTS

Many people contributed to the successful completion of the past three years of post-fire weed management activities within the 2003 Okanagan Wildfire projects. These individuals represent a wide variety of affiliations and backgrounds.

The primary funding body for all three-project sites was provided through the Inter-Ministry Invasive Plant Committee for the provincial government. Other financial contributions were received from Forests for Tomorrow, Agriculture Environmental Partnership Initiative, The Nature Trust of BC (BC Conservation Corps and Human Resources Development Canada Funding), BC Ministry of Transportation, BC Ministry of Environment, BC Ministry of Forests and Range, BC Ministry of Agriculture and Lands, Terasen Gas, BC Transmission Corporation, and FortisBC.

A SUMMARY OF ACUTE RISK OF FOUR COMMON HERBICIDES TO BIRDS AND MAMMALS

Shawna L. Bautista[1]

ABSTRACT

USDA Forest Service risk assessments were used to characterize risks to wildlife from use of dicamba, glyphosate, triclopyr, and 2,4-D herbicides. Ten different exposure scenarios in the risk assessments quantified potential acute doses of these herbicides to mammals and birds. Estimated doses of dicamba and glyphosate exceeded toxicity thresholds only at maximum application rates. Triclopyr exceeded toxicity thresholds in two scenarios, and 2,4-D in eight scenarios, at typical application rates. Vegetation-eating and insect-eating birds and mammals were at most risk. Estimated doses to predatory birds consuming small mammals or fish did not exceed toxicity thresholds for any herbicide analyzed. Estimated doses sometimes exceeded doses reported to cause mortality or adverse effects to reproduction or internal organs. Analysis was conducted at a broad scale, so estimated doses are unlikely to result in most field applications. However, results suggest that large area broadcast or aerial spray applications of some herbicides could expose wildlife with small foraging areas to unacceptable risks. Awareness of potential risks to wildlife allows invasive plant managers to design projects to minimize or avoid these risks. Results of the analysis were used to help develop management standards for use of herbicides on National Forests in Oregon and Washington. On these National Forests, dicamba and 2,4-D are not approved for use on invasive plants and broadcast spray of triclopyr is prohibited. Spot spray and selective applications of triclopyr are permitted.

KEYWORDS: Herbicides, toxicology, wildlife, risk assessment.

INTRODUCTION

The USDA-Forest Service Pacific Northwest Region (Oregon and Washington) recently reviewed and updated management direction for its invasive plant program. Herbicide risk assessments conducted prior to 2005 were used to characterize the relative potential risks to birds, mammals and other wildlife from use of any of twelve herbicides used to treat invasive plants. Results[2] of the analysis for acute exposures to dicamba, glyphosate, triclopyr, and 2,4-D are notable and reported here. Chronic exposure and risk were also analyzed in the assessments (see USDA Forest Service 2005, Appendix P) but are not discussed here.

The analysis indicated that high doses of these herbicides have the potential to affect internal organs, reproduction, or health, or increase risk of mortality for insect- and grass-eating mammals and birds. Project planners considering use of herbicides to control invasive plants may not be aware of these potential risks because they have not been widely reported. Increased awareness can help applicators reduce herbicide risks to birds and mammals in the field.

The analysis was used to support the development of regional standards and practices to minimize or eliminate risk to free ranging wildlife from herbicide use on National Forests in Oregon and Washington. Risks were compared to the need for effective invasive plant control across the

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[2] Results discussed here are based on information available prior to 2005. Herbicide risk assessment is a rapidly changing science and information currently available may lead to different conclusions regarding risk to birds and mammals.

region and factored into the Regional Forester's Record of Decision (USDA 2005b) regarding use of these herbicides on National Forests in Oregon and Washington. The broad scale of the decisions dictated a broad, general scale of analysis. Analysis conducted at a project-level scale could yield different results in terms of risk to birds and mammals.

METHODS

The USDA Forest Service used methods recommended by the National Research Council of the National Academy of Sciences to conduct the ecological risk assessment and characterize risk to wildlife (National Research Council 1983, SERA 2001).

Toxicity information, including data submitted to the United States Environmental Protection Agency (EPA) for registration, was used to establish a dose-response threshold (toxicity threshold) for types of wildlife found on National Forests in Oregon and Washington. When sufficient data existed, the toxicity threshold was the "no-observable-adverse-effect-level" (NOAEL) rather than a lethal dose measure, such as an LD_{50}.[3] The NOAEL from the most sensitive effect from the most sensitive test species was used to establish the threshold (e.g., for the herbicide glyphosate, the NOAEL threshold was diarrhea in rabbits; see table 1).

The acute threshold values for dicamba, glyphosate, and triclopyr were taken from the respective risk assessments without modification (SERA 2003a, SERA 2003b, SERA 2004). The risk assessment for 2,4-D did not identify a specific NOAEL for mammals, so dose-severity values in the risk assessment (SERA 1998, p. 3–52) were used to determine the likelihood of an adverse effect. Also, the 2,4-D risk assessment contains very little information specific to birds, so data cited in Weed Science Society of America (2002), were used as the threshold value. Two forms of triclopyr (ester and acid) have somewhat different toxicities to birds and different threshold values were used for each, as identified in the risk assessment.

The analysis for the invasive plant program used ten exposure scenarios to quantify acute doses to wildlife from herbicide exposure. Exposure scenarios varied by exposure mechanism (e.g., feeding, direct spray), animal type and body size (SERA 2001). For example, one scenario is a deer-sized mammal consuming vegetation sprayed with herbicide, with the animal consuming solely the contaminated vegetation. While such a scenario may not be likely to occur on the National Forests, it provided a consistent worst-case basis for comparing degree of risk associated with the different herbicides.

Doses were estimated for applications at the average rate used in Forest Service herbicide applications (typical) and at the highest rates included in the risk assessments (highest) (table 2). The highest rates included in the risk assessments are rarely used in Forest Service applications, but had been reported in the past and were included in the analysis.

For each of the ten scenarios, the acute dose an animal could receive was compared to toxicity information from laboratory studies. Doses above the toxicity threshold were considered to pose a risk of adverse effects. Exposure scenarios produced a range of estimated doses, listed as lower, central, and upper estimates in the risk assessments. Generally, lower and central estimates of dose would not exceed toxicity thresholds, but the upper range of estimated doses would exceed the thresholds. Consistent with a "worst case" analysis approach, results reported here include instances in which the threshold was exceeded only in the upper range of estimated doses.

The number of scenarios in which an estimated dose exceeded a threshold was recorded as a general measure potential risk to birds and mammals for each herbicide. When estimated acute doses exceeded these threshold values, the actual estimated dose was compared with available toxicity data to determine the nature or magnitude of potential adverse effects.

RESULTS

At the typical application rates, none of the acute scenarios presented unacceptable risks to wildlife when using dicamba or glyphosate (table 3). At the typical rate, triclopyr

[3] LD_{50} is the dose of a toxin that will kill 50 percent of test organisms within a designated period of time. A lower LD_{50} indicates a more toxic compound.

Table 1—Acute toxicity threshold values from laboratory studies used to determine acute risk for the invasive plant program in the Pacific Northwest Region of the USDA Forest Service

Herbicide	Endpoint	Dose	Species	Effect Noted at higher dose (usually LOAEL[a])
Mammals				
Dicamba	NOAEL	45 mg/kg	Rat	Decreased pup growth at 105-135 mg/kg
Glyphosate	NOAEL	175 mg/kg	Rabbit	Diarrhea, and some mortality to dams, at 350 mg/kg
Triclopyr	NOAEL	100 mg/kg	Rat	Malformed fetuses at 300 mg/kg
2,4-D	"no effects likely"	0.1 mg/kg	various mammals	Increase thyroid weight and/or decreased testicular weight at doses greater than 0.1 and less than 1.0
Birds				
Dicamba	NOAEL	92 mg/kg	Mallard	Decreased hatchability and survival of young at 184 mg/kg
Glyphosate	NOAEL	562 mg/kg	Mallard & Quail	No effects at highest dose
Triclopyr ester (BEE)	0.1 LD_{50}	38.8 mg/kg	Quail	50 percent mortality at 388 mg/kg[b]
Triclopyr acid (TEA)	0.1 LD_{50}	53.5 mg/kg	Quail	50 percent mortality at 535 mg/kg[b]
2,4-D	0.1 LD_{50}	56.2 mg/kg	Mallard & Quail	50 percent mortality at 562 mg/kg

[a] LOAEL – lowest observable adverse effect level

[b] There is some confusion in the risk assessment as to whether the 535 mg/kg for TEA and the 388 mg/kg for BEE are interpreted as LC50's or NOAELs. However, the 1998 RED for triclopyr (EPA 1998) lists as LC50's for birds as 5357 ppm (p. 73) and 3884 ppm (p. 74), which can be converted to mg/kg based on birds consuming 10 percent of their body weight per day.

Source: SERA 1998, SERA 2003a, SERA 2003b, SERA 2004, Weed Science Society of America 2002.

Table 2 - Application rates used in calculating doses to birds and mammals

Herbicide	Typical application rate reported in risk assessment (lb ae/ac[a])	Highest application rate (lb ae/ac) reported in risk assessment
Dicamba	0.3	2.0
Glyphosate	2.0	7.0
Triclopyr	1.0	10.0
2,4-D	1.0	2.0

[a] pounds of acid equivalent per acre

exposures exceeded thresholds in two scenarios, both of which assume that 100 percent of a bird's diet (either grass or insects) has been directly sprayed. Exposure to 2,4-D at the typical rate resulted in eight of ten acute exposure scenarios where estimated dose exceeded the toxicity threshold.

At the highest application rates, triclopyr exposures exceeded toxicity thresholds in five acute scenarios. Dicamba exposures exceeded toxicity thresholds in four scenarios at the highest application rate. Glyphosate exposures exceeded toxicity thresholds in three scenarios at the highest application rate. Exposures to 2,4-D exceeded toxicity thresholds in eight scenarios at the highest application rates.

Table 3—Acute exposure scenarios and application rates in which estimated doses exceeded toxicity thresholds. (✱ - threshold exceeded at typical and highest application rates; ♦ - threshold exceeded at highest application rates only; -- estimated doses were below threshold)

Scenario/Animal	Dicamba	Glyphosate	Triclopyr	2,4-D
Direct spray, small mammal	--	--	♦	✱
Consume contaminated vegetation				
small mammal	--	--	--	✱
large mammal	♦	♦	♦	✱
large bird	♦	--	✱	✱
Consume contaminated water				
small mammal	--	--	--	✱
Consume contaminated insects				
small mammal	♦	♦	♦	✱
small bird	♦	♦	✱	✱
Consume contaminated prey				
carnivore (consumes small mammal)	--	--	--	✱
predatory bird (consumes small mammal)	--	--	--	--
predatory bird (consumes fish)	--	--	--	--

For most scenarios, doses exceeded the NOAEL threshold, but did not necessarily cause a specific adverse effect on any wildlife groups. Some scenarios resulted in theoretical exposures that reached known levels of adverse effects, including potential mortality.

For dicamba, a large mammal or bird consuming only treated vegetation would receive a dose that was approximately equivalent to doses that caused adverse effects to reproduction. Doses to small mammals and birds consuming only contaminated insects for a day exceeded the level for adverse effects to reproduction. Thus, for both birds and mammals, adverse effects on offspring are plausible, in the context of these conservative scenarios, for exposures associated with maximum application rates (SERA 2004).

Glyphosate applied at the highest application rate could expose large herbivorous mammals feeding exclusively in the treatment area to a dose that has caused mortality in tests involving rabbits. While this estimated dose is well below the reported LD_{50} for mammals (2,000 mg/kg), mortality in some animals is plausible; other lesser effects (e.g., diarrhea) are likely.

The typical application rate of triclopyr resulted in a dose to herbivorous and insectivorous birds that exceeded the threshold value, but did not reach a lethal dose. However, at the highest application rate, the upper range of estimated doses to birds exceeded the acute lethal dose measure (LD_{50}). The maximum application rate of triclopyr resulted in doses to large herbivorous and small insectivorous mammals that exceeded the level reported to cause malformed fetuses in rats (Bryson 1994 as cited in SERA 2003b).

Estimated doses to mammals of 2,4-D at the typical and highest rates equaled or exceeded doses reported, in laboratory studies, to cause effects such as mild signs of systemic toxicity, increased thyroid weight, decreased testicular weight, decreased weight gain, sub-clinical pathology to kidney and liver, or damage to other internal organs.

Doses of 2,4-D to birds at typical and highest rates exceeded 0.1 of the acute LD_{50}, but did not exceed the LD_{50}. No direct mortality to birds is likely; the potential for lesser effects is unknown.

None of these four herbicides exceeded any toxicity thresholds for fish-eating birds (e.g., bald eagles, ospreys) or raptors that eat small mammals (e.g., northern spotted owls, great gray owls) at typical or highest application rates.

CONCLUSION

Herbicide risk assessments used exposure scenarios to quantify doses to wild birds and mammals. In some scenarios, the estimated doses received by mammals and/or birds exceeded those known to cause adverse effects. The scenarios used are conservative, by design, to produce a "worst case" analysis. The exposure scenarios do not account for mitigating factors, such as animal foraging behavior, action of the herbicide, seasonal presence, timing and methods of application, and strict adherence to label advisories. For example, a deer is unlikely to feed exclusively within an area immediately after treatment, nor would an insectivorous bird forage exclusively on insects that had been inadvertently sprayed with herbicide. Therefore, the estimated doses from the scenarios would not necessarily translate to noticeable effects to individuals or populations in the field. Field studies evaluating the effects of herbicide use on free-ranging wildlife have attributed changes in populations to habitat alteration rather than direct toxic effects (e.g., Johnson and Hansen 1969, Lautenschlager 1993, McMurray et al.1993, Sullivan 1990).

On National Forests in the Pacific Northwest, herbicides are unlikely to be applied to treat invasive plants over an area large enough to encompass the entire day's forage for an herbivorous or insectivorous bird or mammal. However, the scenarios cannot be dismissed. For instance, if a broadcast treatment of dicamba or triclopyr were applied to a large area aerially or by ground equipment, a bird could encounter and feed upon enough contaminated food to receive a potentially harmful dose. Similarly, broadcast applications of triclopyr or dicamba could pose a risk to herbivorous animals if the application area was large enough to encompass their foraging area (e.g., a meadow).

The USDA Forest Service Pacific Northwest Regional Forester used this information to guide herbicide use for invasive plant management (USDA Forest Service 2005b). All applications of 2,4-D and dicamba were prohibited, along with aerial and broadcast application of triclopyr (selective applications of triclopyr, which far reduce the potential for exposure to birds and mammals, were permitted). The Regional Forester documented her rationale for these decisions based on the relative cost, effectiveness, and need for and risks associated with each of the herbicides (ibid.). The Regional Forester's 2005 Record of Decision and supporting documentation are available at: http://www.fs.fed.us/r6/weeds/

The risk assessments may be further used to guide implementation of invasive plant treatment projects by helping land managers avoid scenarios that could result in harmful exposures to wildlife.

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GOT MILK THISTLE? AN ADAPTIVE MANAGEMENT APPROACH TO ERADICATING MILK THISTLE ON DAIRIES IN KING COUNTY, WASHINGTON STATE

Dennis Chambreau and Patricia A. MacLaren[1]

ABSTRACT

Milk thistle, *Silybum marianum* (L.) Gaertner, can be an aggressive pasture and rangeland weed. Milk thistle is native to southern Europe, the Mediterranean region and Northern Africa. Its current distribution includes most temperate areas of the world. In the western United States, it is believed to have been introduced in cattle feed (Bean 1985). In Washington State, the largest occurrence of milk thistle is found on the Enumclaw plateau in southeastern King County. Milk thistle can form dense stands and reduce forage availability by shading pasture grasses (Roché 1991). Milk thistle is a nitrate accumulator and can cause nitrate poisoning if ingested by grazing animals. In Washington State, milk thistle is a Class A noxious weed and eradication is required by state law (RCW 17.10).

KEYWORDS: Milk thistle, *Silybum marianum*, eradication, aminopyralid, Washington State.

INTRODUCTION

Milk thistle is a winter annual or biennial, germinating throughout the year in western Washington State. It is mainly confined to high fertility soils and frequently establishes on disturbed areas with higher than normal soil nitrogen levels (Bean 1985). In King County milk thistle was introduced into the dairy farming area near the town of Enumclaw and has spread in these heavily fertilized pastures. These soils have a very high nitrogen content due to the constant application of liquid manure from the waste lagoons of the dairies. These pastures are continually disturbed by cows and equipment. Seed dispersal is the only means by which milk thistle spreads. Means of dispersal include water, mud, hay, vehicles, machinery and animals.

Milk thistle can be identified from other thistles by its distinctive white veins on dark green leaves. The broad, lobed leaves can grow up to 20 inches long and ten inches wide. The leaf margins are tipped with spines up to 0.5 inches long. Each stem ends in a solitary purple flower head approximately two inches in diameter. Milk thistle flower heads are unique in having broad leathery bracts tipped with spines up to two inches in length. In our region flowers are produced from late April through October. Each terminal head of the plant produces approximately 100 seeds and ten to 50 heads are produced per plant (Bean 1985). Because the seeds are heavy (20 mg), and have a deciduous pappus, most seeds fall near the parent plant. Milk thistle seed has the potential to remain viable in the soil for up to nine years. Seeds germinate from late summer through winter, whenever temperature (32° to 86° F) and moisture conditions are favorable. Plants overwinter as rosettes which may reach three feet in diameter (Roché 1991).

ERADICATION EFFORTS IN KING COUNTY

In King County, approximately seven acres are infested in an area of eight square miles. Eradicating these infestations

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is the management goal as mandated by state weed control law. Eradication is difficult for a plant species as well established as milk thistle in King County and requires persistence and dedication. King County Noxious Weed Control Program partners with landowners through education, technical and control assistance, surveying and monitoring. Our goal is to stop seed production, exhaust the seed bank and prevent new infestations and introductions.

The first plants in the Enumclaw area were discovered on the roadside in 2001. This was thought to be an isolated infestation, but a large parent infestation was found in 2003. Beginning in 2003, the infestations were surveyed, landowners were provided with 2,4-D herbicide and results monitored. These efforts were not sufficiently reducing the weed population, and in 2006 an adaptive management strategy utilizing strong partnerships with landowners and new tools on the market was initiated. This is an integrated management approach that utilizes chemical, cultural and manual techniques.

Three areas with germinating seedlings and established rosettes were treated with clopyralid in October 2005 to test the efficacy of fall applications of this herbicide. It is hoped that the residual activity from the clopyralid will help control germinating seedlings. In April 2006, known infestations were surveyed and 23 landowners were provided 2,4-D. As an adaptive management trial on the largest infestation, five acres were treated with aminopyralid herbicide at a rate of five ounces per acre. Aminopyralid does not have grazing restrictions for lactating animals. The aminopyralid was slow-acting and the soil residual effects are not yet known. In May, plants missed by the initial applications were surveyed and treated with a tank mix of aminopyralid plus 2,4-D to achieve more rapid herbicide activity. In June, when plants had bolted and flower heads were visible, surveys of the entire infested area were conducted for survivors and new infestations. When plants were found, viable seed heads were removed and bagged, and the plants were dug out or treated with aminopyralid plus 2,4-D. In October, aminopyralid will be applied to rosettes and seedlings at all infested sites.

In conclusion, with a strategy of exhaustive surveys and meticulous control methods to prevent flowering and seed production, milk thistle on the Enumclaw plateau can be eradicated as the seed bank becomes exhausted.

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CONTROLLING INVASIVE PLANTS WITHOUT HERBICIDES, CEDAR RIVER MUNICIPAL WATERSHED

Sally Nickelson[1], Heidy Barnett, David Chapin, Bill Richards, and Dwayne Paige

ABSTRACT

The >91,000-acre Cedar River Municipal Watershed is managed to supply Seattle's drinking water while restoring fish and wildlife habitat, natural ecosystem processes, and native biological diversity. Invasive plants threaten all three of these restoration goals. Currently no herbicides are used within the watershed, so we are exploring alternative methods to control three invasive species. In 2004 we used geotextile fabric to cover several large Bohemian knotweed (*Polygonum* × *bohemicum*) (J. Chrtek & A. Chrtková) patches in a wetland. We monitored the project every three weeks during the growing season, crushing any growth under the fabric and pulling all small starts outside the fabric. After the first growing season, there was no growth under the fabric. After three seasons, the pulling, along with growth of competing native vegetation, has greatly reduced the knotweed outside the fabric. Tansy ragwort (*Senecio jacobaea*) occurs along many of the roads in the watershed. We pulled all plants annually from 2002 through 2006 and are monitoring this method's effectiveness and cost efficiency. In fall of 2006 we will establish four biocontrol areas in high density patches, where tansy flea beetles (*Longitarsus jacobaeae*) will be released and results monitored. Scotch broom (*Cytisus scoparius*) grows along roads and in other disturbed areas in the watershed. In 2004 we began hand-cutting Scotch broom at the ground surface during or shortly after flowering. There was little or no regrowth when the plants were large and competing native vegetation present, as well as in sites where the plants only recently established and the seed bank was minimal.

KEYWORDS: Knotweed, tansy ragwort, Scotch broom, herbicides.

INTRODUCTION

The Cedar River Municipal Watershed, located approximately 30 miles east of the city of Seattle, supplies 70 percent of Seattle's drinking water (over 100 million gallons per day). It encompasses >91,000 acres, with elevations ranging from 538 to 5,447 feet above sea level (fig. 1). It is predominately forested and was logged extensively from the 1880s through the mid-1990s, with only about 14,000 acres of old-growth forest remaining. One of the legacies of the extensive logging is over 600 miles of road within the watershed. Habitat types in addition to forest include lakes, ponds, wetlands, meadows, and talus slopes.

The city manages the watershed under a 50-year Habitat Conservation Plan (HCP), signed in 2000. The primary goals of the HCP are to restore natural ecosystem processes, functions, and fish and wildlife habitat, as well as maintain and foster native biodiversity. No logging for commercial purposes will be conducted, although we will thin some dense young forest stands to facilitate older forest habitat conditions. In addition, we will create snags, downed wood, and canopy gaps, and plant native species to restore and enhance wildlife habitat. As part of the HCP, over 200 miles of road will be decommissioned by 2020.

Numerous invasive plants are present in the watershed, including tansy ragwort, Bohemian knotweed, Scotch

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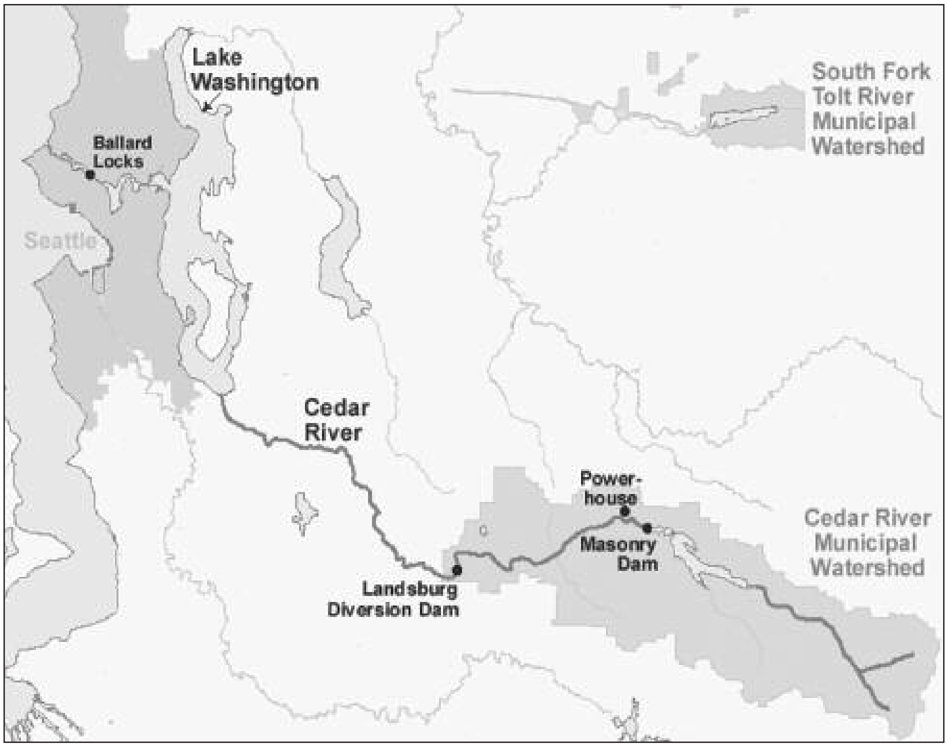

Figure 1—Location of Cedar River Municipal Watershed.

broom, yellow or meadow hawkweed (*Hieracium caespitosum* = *H. pratense*), orange hawkweed (*Hieracium aurantiacum*), Himalayan blackberry (*Rubus discolor*), evergreen blackberry (*Rubus laciniatus*), and Eurasian watermilfoil (*Myriophyllum spicatum*). Currently no herbicides are used within the watershed. Control methods we have employed include pulling, cutting, deflowering, and shading with geotextile fabric. In the future we will use biocontrol for some of the invasive species. Although we are monitoring the success of our invasive plant control program, our efforts are intended to maximize control within a limited budget rather than provide answers to research questions.

A KNOTWEED CONTROL PROJECT WITHIN A WETLAND

Bohemian knotweed poses one of the most significant ecological threats to riparian and wetland habitats in the municipal watershed. It can rapidly dominate riparian areas, forming dense monocultures that are little used by native wildlife species. In addition to simplifying habitat structure, knotweed may alter the habitat of adjacent streams because of the different chemistry, timing, and quantity of leaf litter input. This could potentially alter the invertebrate community and consequently affect the native fish populations, including threatened salmonids.

In the early 1900s a logging road (Road 16) was constructed through the Rock Creek wetland, a large wetland complex in the western, lower-elevation portion of the watershed. This road compromised wetland hydrology and habitat connectivity for many decades. In 2002 a road deconstruction project was initiated to restore the natural hydrology within the wetland. Over 1,200 feet of Road 16 was heavily infested with Bohemian knotweed; therefore, we combined a knotweed eradication project with the road deconstruction (fig. 2). Goals of the project were to restore the natural hydrology, eliminate the knotweed infestation, reestablish the native plant community, and restore natural ecological functioning. In the fall of 2002 we deconstructed the road using heavy equipment, removing all culverts and

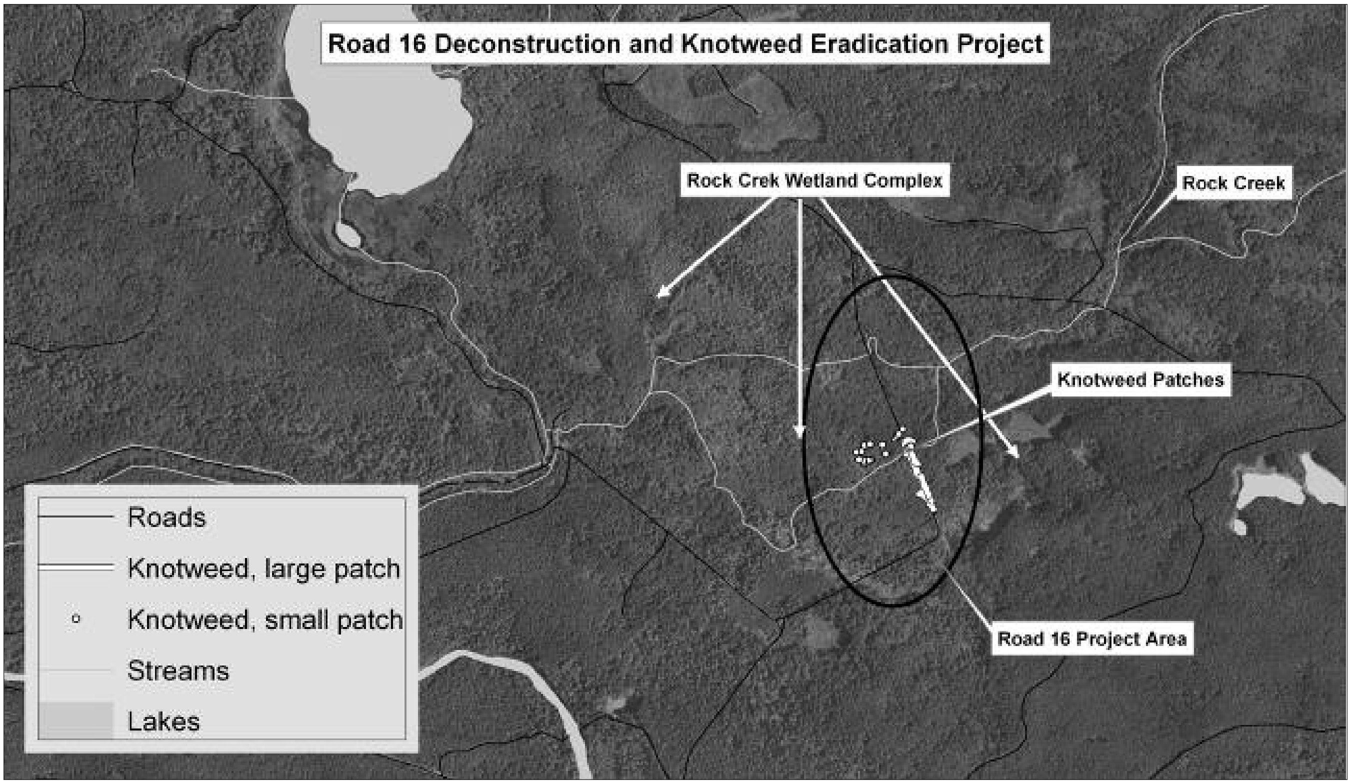

Figure 2—Map of the Road 16 deconstruction and knotweed control project.

some road material. This included excavating the majority of the large rhizomes of the knotweed and transporting them off site to an old gravel pit, where they were buried six to ten feet deep with the road material.

As expected, knotweed along the deconstructed road bed grew back from the small root and stem fragments that remained after the heavy equipment phase of the project was complete. The infested area was approximately 1.25 times that prior to the road excavation because the fragments had been spread by the equipment. The majority of the small plants were along the road edges adjacent to the forest, in the same locations as the original infestation. In 2003 we hosted two volunteer events (in May and July) and all the small knotweed plants were pulled. It was apparent, however, that this level of effort would be insufficient to control the infestation. Prior to this project we had tested the efficacy of using geotextile fabric (road cloth) to control the knotweed, with promising initial results. In the spring of 2004 we installed >31,000 square feet of fabric in an attempt to starve the small remaining roots of sunlight. We placed the fabric very loosely over the heavily infested areas, which allowed some growth under the cloth. We found that if the cloth is stretched tightly, the plants easily puncture the cloth. But if it is left loose, this permits some plant growth but keeps the cloth intact. This allows us to maintain the cloth by simply walking over the fabric, stomping the new growth and breaking the stems. We covered the heavily infested areas along the road edges, leaving the center of the old roadbed uncovered to function as a wildlife travel corridor (fig. 3). A variety of large mammals, including elk (*Cervus elaphus*), deer (*Odocoileus hemionus)*, black bear (*Ursinus americanus*), cougar (*Felis concolor*), and bobcat (*Lynx rufus*) use the wetland and travel frequently along the old roadbed. We wanted to keep the animals off the fabric as much as possible, to minimize tearing of the fabric.

We monitored the project every two weeks during the remainder of the 2004 growing season. Some growth (~two

Figure 3—Photograph of the knotweed covering at the Road 16 project.

feet) occurred under the fabric early in the summer. During each visit we stomped down all growth under the fabric and pulled all plants from the center of the road and around the edges of the fabric. We used three types of fabric: a heavy black plastic (6 ml polyethylene sheeting) and two types of geotextile fabric, woven (product LP200 obtained from Layfield Plastics) and non-woven (6 oz weight, product LP6 from Layfield Plastics). We found the heavy plastic tore very easily, and several pieces had to be replaced by the more durable geotextile fabric. The woven geotextile fabric allowed less light penetration, and consequently had less growth under it. However, it was very stiff, difficult to work with, and shed small plastic filaments from the edges. The non-woven fabric was the best overall for durability, ease of use, and efficacy of control. A slightly heavier grade of non-woven fabric (LP7), which provides more shade, will likely be the best for overall performance and ease of use.

In 2005 and 2006 we monitored the project every three weeks during the growing season (May to October). There was no growth under intact fabric, although some canes grew through holes made by wildlife. We did not conduct growth measurements, but observed that both the number and size of plants outside the fabric decreased both as the growing season progressed, and from 2005 to 2006. In May 2006, we removed the fabric from three small patches and no growth of knotweed was observed during the remainder of the growing season. In 2007 we will remove fabric from larger areas and continue to monitor every three weeks. We anticipate we will need to continue monitoring the site for

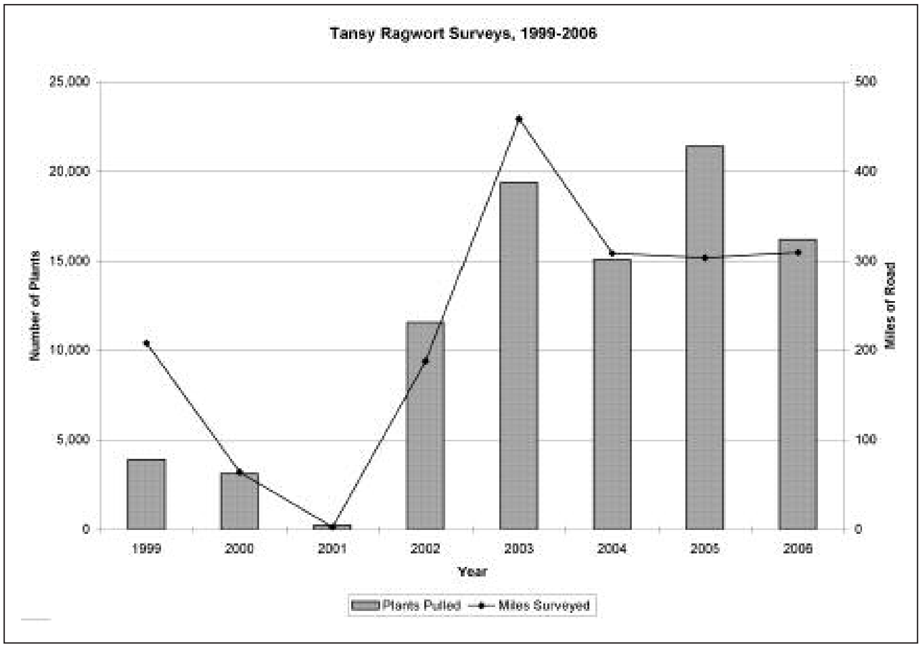

Figure 4—Summary of tansy ragwort survey and control efforts, 1999 – 2006.

a minimum of five more years to ensure that we have completely eradicated the knotweed. In 2006 the gravel pit where the old rhizomes from the project had been buried now had growth over approximately half of the pit. So burying the rhizomes under a large amount of fill was not sufficient to kill them.

CONTROLLING TANSY RAGWORT ALONG ROADS AND RIVERS

Tansy ragwort occurs extensively along roads and some rivers in the watershed, and may spread into recently disturbed areas within the forest (e.g., areas of windthrow after a major wind storm). This plant can be toxic to ungulates and several insect species, and control is legally required in King County. In 1999 we began to survey the extent of the infestation and initiate some limited control. Little work was completed in 2000 or 2001 due to funding and staffing shortages. In 2002 we initiated a tansy ragwort control project. Project goals included complying with noxious weed laws, mapping the distribution and density of tansy ragwort within the watershed, tracking population trends and responses to control efforts, identifying the most cost-effective control methods, and recommending management actions to decrease the spread of tansy ragwort. Since 2002 we have annually counted, mapped, and pulled all tansy ragwort plants (fig. 4). We cut off all flowers and disposed of them in a sealed bag, leaving the stems and roots to desiccate in the road bed. The highest densities have consistently been along the most heavily traveled roads at lower elevations in the western portion of the watershed (fig. 5). At higher elevations in the eastern portion of the watershed there are only two high-density patches, with the remaining isolated patches usually consisting of four or less plants.

No control of tansy ragwort along a specific road segment from 1999 to 2003 resulted in a large increase in both area covered and density of plants (figs. 6a–b). Pulling all tansy plants along this road from 2003 through 2006 resulted in far fewer high-density segments (fig. 6c). We plan to continue pulling all low-density areas, but we will be creating biocontrol areas in the high-density locations by releasing tansy flea beetles under the guidance of the Washington State University Extension biocontrol coordinator for western Washington. We will clip the flowers in these areas to prevent seed spread, but allow the plants to become perennial to serve as hosts for the beetle. We anticipate that in approximately five years the beetle populations will build

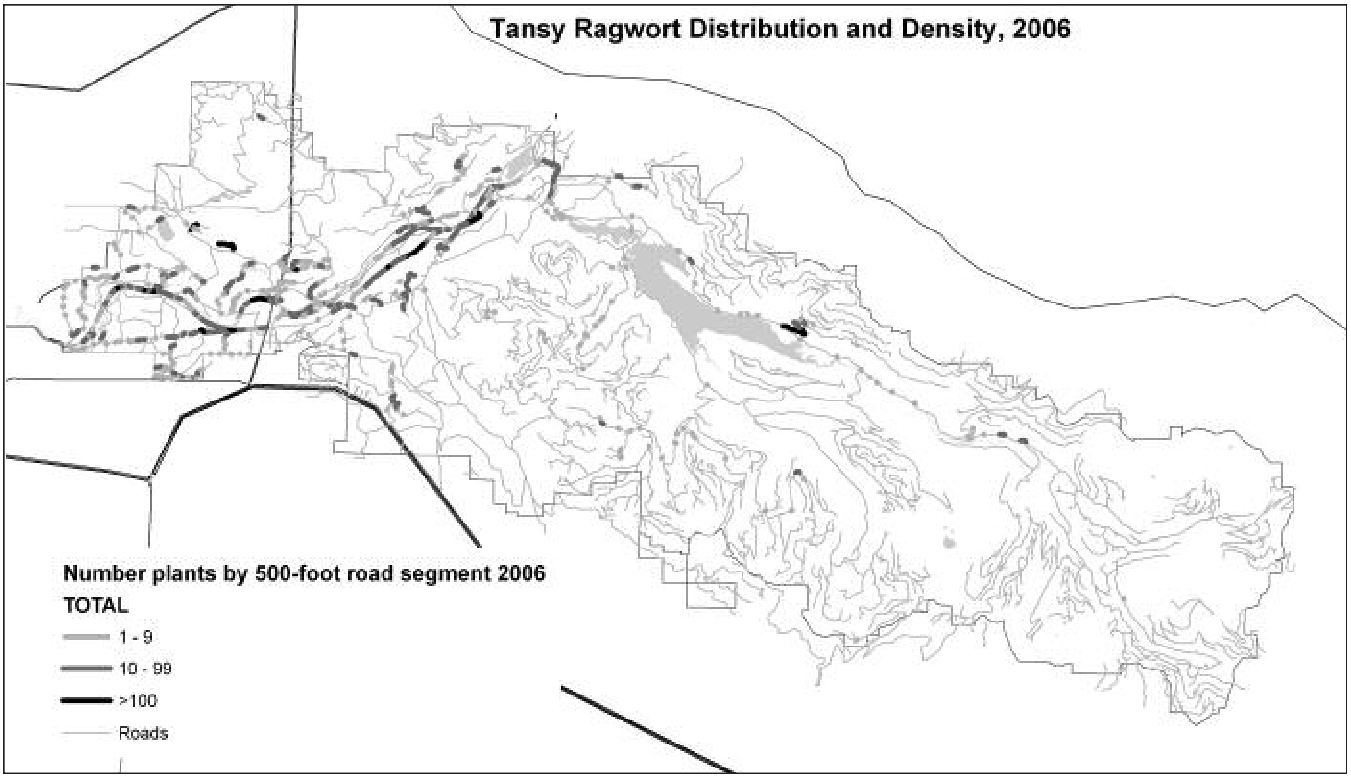

Figure 5—2006 Tansy ragwort distribution and density in the Cedar River Municipal Watershed.

to a level where we will no longer need to do major control efforts.

SCOTCH BROOM CONTROL PROJECTS

Scotch broom out-competes native vegetation in several sunny, dry areas in the watershed. It can invade disturbed areas within the forest (e.g., windthrow) and provides poor forage for most wildlife species. In 2004 we began a Scotch broom control project in the watershed. Project goals were to map all Scotch broom locations within the watershed, try several different removal techniques, eliminate Scotch broom from the higher elevation eastern portion of the watershed where populations are small, and eliminate it from key habitats in the western watershed. Initially we pulled the larger plants with a weed wrench, but found that the soil disturbance appeared to stimulate the seed bank, resulting in a large number of small plants the following year. We found that cutting the larger plants at the ground surface during flowering killed most plants, and in areas with competing native vegetation little growth from seed occurred. In two areas that had only recently been invaded, we found that cutting the larger plants and pulling the small plants eliminated the infestations within two years.

CONCLUSIONS

Four years of attempting to control three invasive species without the use of herbicides has had mixed results. Relatively small patches of Bohemian knotweed appear to be greatly suppressed after three years of shading with geotextile fabric. It remains to be seen how long this treatment will be required to kill all the rhizomes. The large expense of purchasing, installing, and maintaining the fabric over several years prohibits the use of this treatment on large patches. We have installed this treatment on many small infestations that pose a high risk to riparian, wetland, and high quality forest habitat in the watershed, and results continue to be promising.

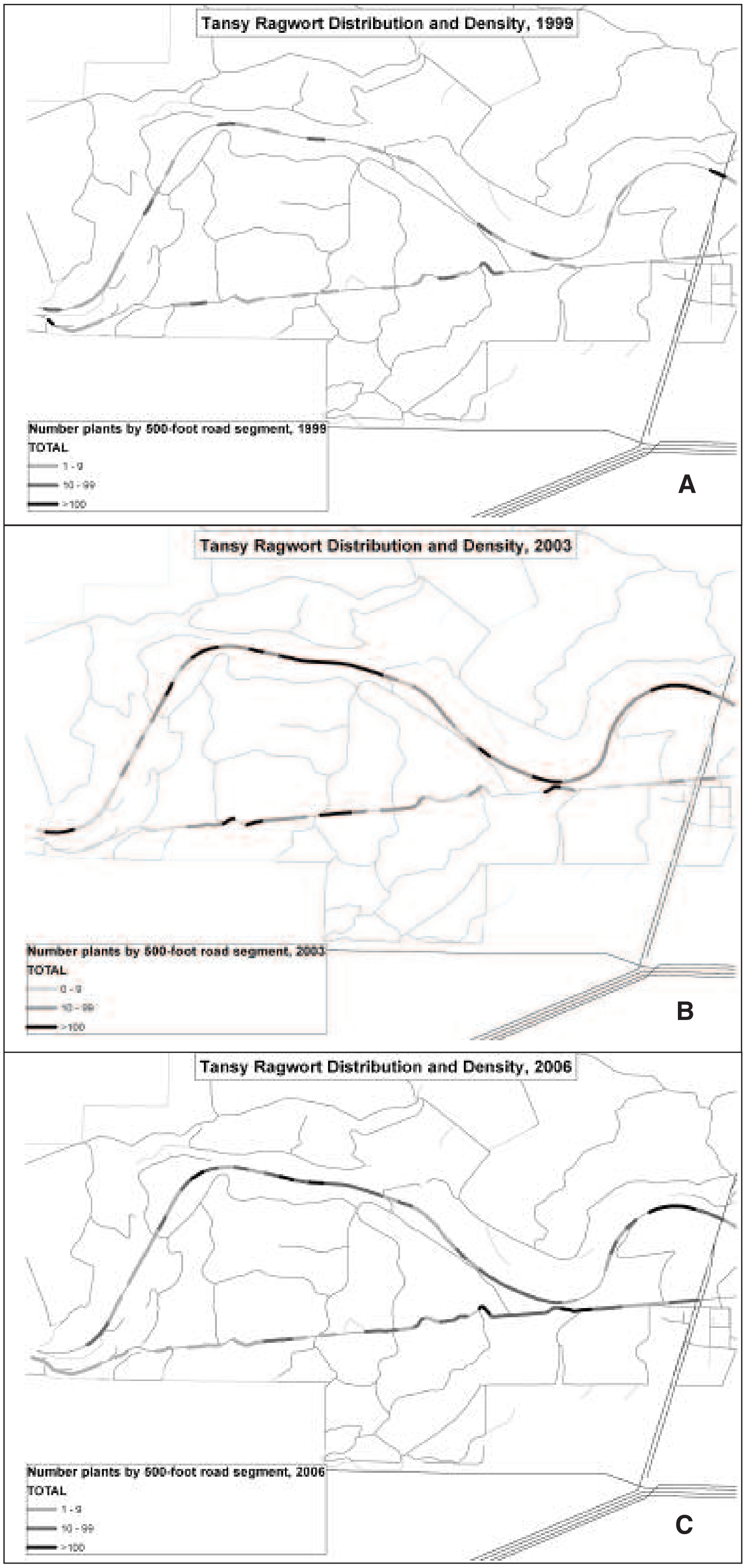

Figure 6—Tansy ragwort distribution and density along selected road segments in (a) 1999, (b) 2003, and (c) 2006.

Pulling tansy ragwort prevents seed production, but is not a cost-effective solution for large patches. We anticipate that once tansy flea beetle populations build to a sufficient level, they will provide better and more cost-effective control over time. Finally, cutting older Scotch broom plants at the ground surface during flowering does appear to kill a significant percentage of the plants. The large seed bank in areas not previously controlled is problematic, and the long-term solution in the watershed will be to plant native vegetation such as conifer trees that will ultimately out-compete the Scotch broom.

DISTRIBUTION AND MAPPING OF INVASIVE PLANTS

Yellow iris (*Iris pseudacorus*) (Lisa K. Scott)

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NON-NATIVE PLANTS ON THE MT. BAKER-SNOQUALMIE NATIONAL FOREST

Tracy L. Fuentes[1], Laura L. Potash[2], Ann Risvold[2], Kimiora Ward[3], Robin D. Lesher[4], and Jan A. Henderson[4]

The Mt. Baker-Snoqualmie National Forest is one of the most visited National Forests. More than 5 million people live within a 70-mile drive. The high visitation rate and the proximity to large numbers of noxious weeds and ornamental plants make the Forest particularly vulnerable to the establishment and spread of invasive plants. To understand the current status and distribution of invasive plants on the Forest, we queried our botany, ecology, and noxious weed databases and GIS layers for all non-native plants. The resulting data were then analyzed by ranger district and by county. We examined the spatial distribution of species to understand how invasive plants may have established and to determine which areas are most vulnerable. In total, 148 non-native species in 28 plant families have been documented. Of these, 34 are noxious weeds, and 25 are garden ornamentals not currently listed as weeds. We identified the following sources of establishment and spread: spread from interstates, highways, and power lines that cross the Forest; spread from floods; spread by animals; spread from vehicles directly accessing the Forest; dumping of yard waste; using materials infested with invasive plant propagules; and the deliberate planting of ornamentals. In addition, several recent land acquisitions included parcels that were already infested with invasive plants.

KEYWORDS: Noxious weeds, invasive plants, non-native plants, Mt. Baker-Snoqualmie National Forest, Washington State.

INTRODUCTION

The Mt. Baker-Snoqualmie National Forest stretches along the western slope of the Cascade Mountains in Washington State, from the Canada/United States border to the northern border of Mt. Rainier National Park (fig. 1). More than 5 million people in Washington State (U.S. Census Bureau 2006) and British Columbia (Statistics Canada 2002) live within a 70-mile drive of the Forest. Given the high visitation rate and the proximity to large numbers of noxious weeds and ornamental plants, the Forest is vulnerable to the establishment and spread of noxious weeds and escaped ornamentals.

Not all non-native plants on the Forest are listed as noxious weeds by federal and state agencies (USDA APHIS 2006, Washington State Noxious Weed Control Board 2006). To be listed as noxious weeds, non-native plants must cause economic and/or environmental harm. Species not listed as noxious weeds may include species which are not believed to cause such harm or for which harm has not yet been recognized.

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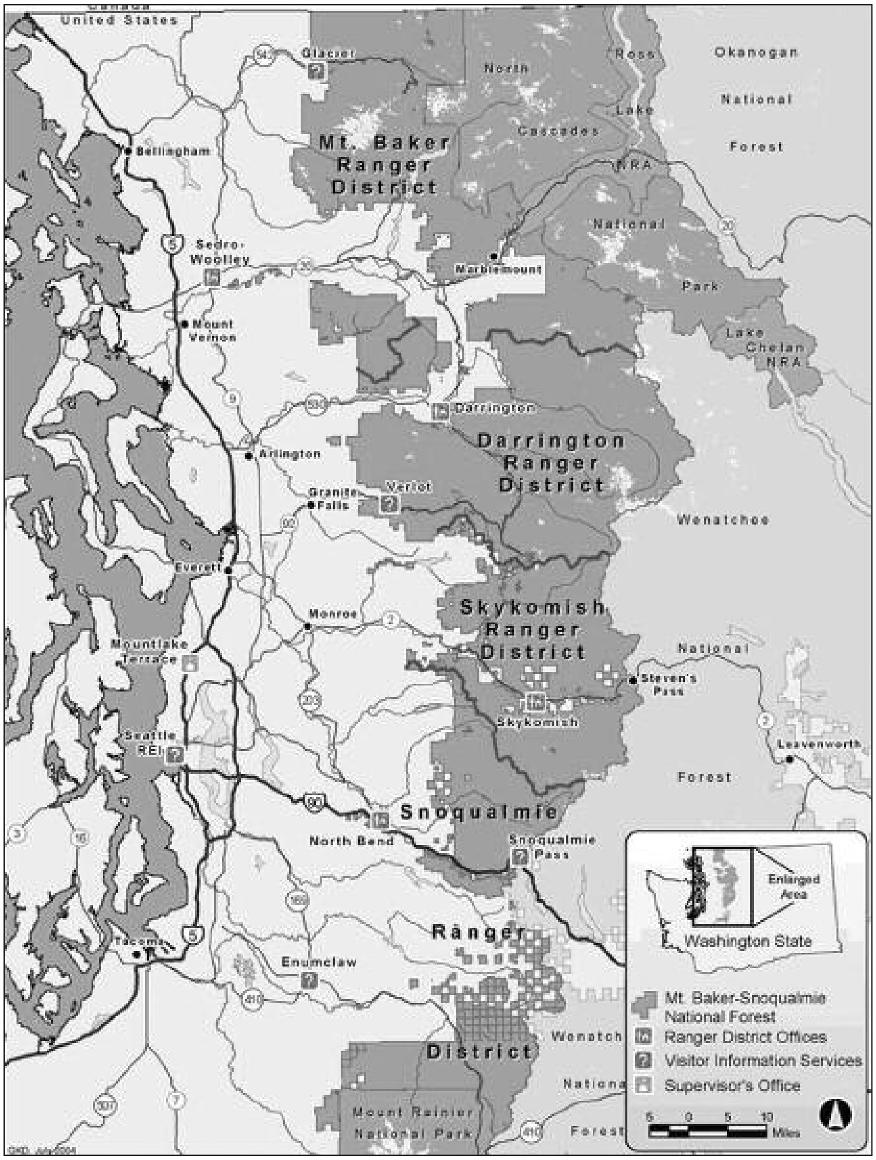

Figure 1—Location of the Mt. Baker-Snoqualmie National Forest in Washington State.

The goals of the Federal Noxious Weed Program (USDA APHIS 2006) are to prevent the introduction of non-native plants into the United States and to prevent the spread of newly introduced invasive plants within the United States. The program focus is to minimize the threat to the nation's agriculture and environment. Species on the federal noxious weed list may not be introduced into the United States or moved between the states. Such importation or movement may be allowed under specific permit conditions.

Washington State's Noxious Weed Board updates the state noxious weed list each year and coordinates education and control efforts throughout the state. The state noxious weed list separates species into three categories, based on their current distribution in the state, their potential for harm, and required control measures (Washington State Noxious Weed Control Board 2006). Class A noxious weeds have limited distribution in the state and a high potential for harm should they become well established. Class B noxious weeds are limited in distribution in parts of Washington State, but very abundant in other parts of the state. Class C noxious weeds are widespread in Washington State. State law requires control of all Class A noxious weed infestations, as well as Class B designates (regions of the state where that species is not well established). County weed boards and districts may also require control of other Class B and Class C noxious weeds.

As a routine part of their duties, the Forest botanists work to prevent noxious weed infestations, to document noxious weed sightings, and to develop noxious weed control plans (USDA Forest Service 2005). To be most effective in preventing new infestations, however, the Forest must not only be able to detect new infestations and new species, but also to predict where and how these species may spread.

Both the Forest Botany and Forest Ecology Programs have high quality, long-term data regarding the distribution of all vascular plants on the Forest. Because of this, we are able to assess where non-native plants occur on the Forest. In addition, the different data collection methods allow us a unique opportunity to assess how different sampling schemes detect non-native plants.

Specifically, we address the following questions:

1) Which non-native vascular plants occur on the Forest?
2) In which ranger districts and counties do they occur?
3) Do the two sampling schemes (botany surveys and ecology plots) detect the same non-native species?
4) Do the botany surveys and ecology plots detect similar numbers of non-native plants?

METHODS

Existing datasets

The botany survey database contains all vascular plant, bryophyte, and lichen species recorded by a professionally trained botanist in a specific area. These areas are usually tied to a specific project: proposed roads, trails, or timber sales, for example. Because project areas are usually easily accessible by vehicle or foot, the survey areas are often associated with roads or trails. Area surveyed ranges from 0.1–712 acres. Survey intensity ranges from complete surveys for small areas to intuitive controlled surveys for larger areas (Nelson 1985). Botany survey dates range from 1990 to 2005.

The ecology plot database contains all vascular plant, bryophyte, and lichen species recorded by a professionally trained plant ecologist in an ecology plot. To classify and characterize the vegetation types of the Forest (Henderson et al. 1992), ecologists established 3,097 plots across the Forest. An additional 1,169 ecology plots have also been established to document benchmarks of species composition and stand conditions, to monitor changes over time, to measure stand growth and productivity, to describe conditions and successional patterns of different plant associations, and to calibrate and validate species habitat models. Ecology plots are deliberately placed to minimize the influence from roads and trails. Plot sizes are typically 0.15–0.20 acre, but range from 0.001 to 0.5 acres, depending on structure and extent of the homogeneous community. Ecology plot installation dates range from 1979 to 2005.

The noxious weed database contains all records of reported noxious weeds on the Forest. Reporters of noxious weeds include botanists, ecologists, county weed program specialists, knowledgeable Forest employees, and knowledgeable members of the public.

Analysis

To understand the current status and distribution of non-native plants on the Forest, we compiled a list of all non-native vascular plants known to occur on the Forest, querying our botany survey, ecology plot, and noxious weed databases for all vascular plants. We classified the resulting list of species as native or non-native, based on the regional flora (Hitchcock et al. 1955–69; Hitchcock and Cronquist 1973), the PLANTS database (USDA Natural Resources Conservation Service 2006), recent work on Pacific Northwest *Hieracium* spp. (Wilson 2006) and professional opinion. Using the existing databases and GIS, we documented the presence of each non-native species by ranger district and by county.

Species whose native or non-native status could not be readily determined were not included in this analysis (i.e., *Poa pratensis*). Because Washington State classifies *Phalaris arundinacea* L. as a noxious weed (Washington State Noxious Weed Board 2006), we followed this usage.

To compare detection rates of area-based and plot-based sampling schemes, we tallied the number of detections of noxious weeds, other non-native plants, and all non-native plants recorded in the botany survey database and in the ecology plot database.

Results for surveys, plots, and weed sightings in Chelan and Kittitas Counties were not included in this analysis. Although the Mt. Baker-Snoqualmie National Forest manages some National Forest System lands in these counties, most are managed by the Okanogan and Wenatchee National Forests.

RESULTS

Species and Distribution

Our analysis indicates that 148 non-native plants have been reported to occur on the Forest (tables 1 and 2). Of these, 34 are noxious weeds (table 1), 25 are escaped garden ornamentals not currently listed as weeds (table 2), and 17 do not appear in the regional flora (table 3, Hitchock and Cronquist 1973). Noxious weeds and other non-native plants occur in every county and ranger district on the Forest (table 4).

Of the reported noxious weeds, the Forest had one known site of a State Class A noxious weed (*Heracleum mantegazzianum* Sommier & Levier), which was controlled in 2001. In addition, 17 State Class B noxious weeds are known to occur on the Forest, as are 13 State Class C noxious weeds. At least 1,080 acres of the Forest are infested with noxious weeds; most of these are along highways, roads, trails, and railroad and powerline right of ways. *Buddleja davidii* Franch., *Polygonum cuspidatum* Sieb. & Zucc., *Polygonum sachalinense* F. Schmidt ex Maxim., and *Polygonum × bohemicum* (J. Chrtek & Chrtková) Zika & Jacobson are mostly known to occur in riparian areas.

Of the 28 plant families represented, Asteraceae and Poaceae had the highest number of non-natives (fig. 2; table 4). In addition, more noxious weeds were members of the Asteraceae than any other plant family.

Nine noxious weeds are ubiquitous on the Forest, occurring on all four ranger districts and in all five counties (table 1): *Cirsium arvense* (L.) Scop., *Cirsium vulgare* (Savi) Ten., *Cytisus scoparius* (L.) Link, *Geranium robertianum* L., *Hypericum perforatum* L., *Hypochaeris radicata* L., *Leucanthemum vulgare* Lam., *Polygonum × bohemicum*, and *Senecio jacobaea* L.

Detection

Neither a project area-specific approach (botany surveys) or a systematic, plot-based approach (ecology plots) detected every single noxious weed or non-native plant known to occur on the Forest (tables 4 and 5). The most frequently detected non-native species on the Forest for both sampling schemes was *Mycelis muralis* (L.) Dumort. (table 4). The most frequently detected noxious weed in the botany survey database was *L. vulgare*, while for the ecology plots it was *C. vulgare* (table 4).

Botany surveys detected 25 different species of noxious weeds; ecology plot installation detected 13 different species (tables 4 and 5).

DISCUSSION

Species and Distribution

Unsurprisingly, most of the known infestations of noxious weeds are concentrated in already disturbed areas on the Forest. However, the actual area occupied by noxious weeds and invasive non-natives is likely to be greater than that of the already documented sites. Many parts of the Forest have not been inventoried for non-native plants. Several highways cross the Forest, and most of the infested areas along the rights-of-way are not included in the Forest total area.

Many species appear to be well established, given the numerous sightings of certain species all over the Forest. However, other species that are well established in the Puget Sound area, but not on the Forest, appear to be invading. These new invaders should be our highest priority to locate and to eradicate.

Although *Impatiens glandulifera* Royle was a known threat to the Forest, based on its presence in King County (King County Noxious Weed Control Program 2005), we had no records of it until 2006. During presentation of this paper at the September 2006 Invasive Plant conference in Seattle, WA, a professional botanist in the audience

Continued on page 113

Table 1—Noxious weeds on the Mt. Baker-Snoqualmie National Forest, by State Weed Class (Washington State Noxious Weed Control Board 2006), Ranger District and County. Species marked with an asterisk (*) are listed by USDA APHIS (2006) as noxious weeds

Family	Scientific Name	Common Name	WA Weed Class	Mt. Baker RD	Darrington RD	Skykomish RD	Snoqualmie RD	Whatcom County	Skagit County	Snohomish County	King County	Pierce County
Buddlejaceae	*Buddleja davidii* Franch.	Butterfly bush	C	X		X	X		X	X	X	
Asteraceae	*Centaurea biebersteinii* DC.	Spotted knapweed	B	X	X	X	X		X	X	X	X
Asteraceae	*Centaurea diffusa* Lam.	Diffuse knapweed	B			X	X			X	X	X
Asteraceae	*Centaurea × moncktonii* C.E. Britton	Meadow knapweed	B				X				X	X
Asteraceae	*Cirsium arvense* (L.) Scop.	Canda thistle	C	X	X	X	X	X	X	X	X	X
Asteraceae	*Cirsium vulgare* (Savi) Ten.	Bull thistle	C	X	X	X	X	X	X	X	X	X
Apiaceae	*Conium maculatum* L.	Poison hemlock	C									
Convolvulaceae	*Convolvulus arvensis* L.	Field bindweed	C				X				X	
Fabaceae	*Cytisus scoparius* (L.) Link	Scot's broom	B	X	X	X	X	X	X	X	X	X
Apiaceae	*Daucus carota* L.	Queen Anne's lace	B	X		X		X			X	
Geraniaceae	*Geranium robertianum* L.	Herb Robert	B	X	X	X	X	X	X	X	X	X
Araliaceae	*Hedera helix* L.	English ivy	C	X				X			X	
Apiaceae	*Heracleum mantegazzianum* Sommier & Levier*	Giant hogweed	A			X					X	
Asteraceae	*Hieracium aurantiacum* L.	Orange hawkweed	B	X	X	X	X	X	X	X	X	
Asteraceae	*Hieracium caespitosum* Dumort.	Meadow hawkweed	B	X	X	X			X	X	X	
Asteraceae	*Hieracium lachenalii* K.C. . Gmel	Common hawkweed	C			X	X			X	X	X
Asteraceae	*Hieracium laevigatum* Willd.	Smooth hawkweed	B			X				X		
Clusiaceae	*Hypericum perforatum* L.	St. John's wort	C	X	X	X	X	X	X	X	X	X
Asteraceae	*Hypochaeris radicata* L.	Spotted cats'-ear	B	X	X	X	X	X	X	X	X	X
Balsaminaceae	*Impatiens glandulifera* Royle	Policeman's helmet	B		X					X		
Asteraceae	*Leucanthemum vulgare* Lam.	Oxeye daisy	B	X	X	X	X	X	X	X	X	X
Scrophulariaceae	*Linaria dalmatica* (L.) P. Mill	Dalmatian toadflax	B			X	X			X	X	
Scrophulariaceae	*Linaria vulgaris* P. Mill.	Butter and eggs	C					X				X
Poaceaeae	*Phalaris arundinacea* L.	Reed canarygrass	C	X	X	X	X	X	X	X	X	
Polygonaceae	*Polygonum cuspidatum* Sieb. & Zucc.	Japanese knotweed	B	X	X	X			X		X	
Polygonaceae	*Polygonum sachalinense* F. Schmidt ex Maxim.	Giant knotweed	B			X				X		

Table 1—Noxious weeds on the Mt. Baker-Snoqualmie National Forest, by State Weed Class (Washington State Noxious Weed Control Board 2006), Ranger District and County. Species marked with an asterisk (*) are listed by USDA APHIS (2006) as noxious weeds (continued)

Family	Scientific Name	Common Name	WA Weed Class	Mt. Baker RD	Darrington RD	Skykomish RD	Snoqualmie RD	Whatcom County	Skagit County	Snohomish County	King County	Pierce County
Polygonaceae	*Polygonum* × *bohemicum* (J. Chrtek & Chrtková) Zika & Jacobson	Bohemian knotweed	B	X	X	X	X	X	X	X	X	X
Rosaceae	*Potentilla recta* L.	Sulfur cinquefoil	B		X	X	X			X	X	
Rosaceae	*Rubus armeniacus* Focke*	Himalayan blackberry		X	X	X	X	X	X	X	X	X
Rosaceae	*Rubus laciniatus* Willd.*	Cut-leaf blackberry		X	X	X	X		X	X	X	
Asteraceae	*Senecio jacobaea* L.	Tansy ragwort	B	X	X	X	X	X	X	X	X	X
Asteraceae	*Senecio vulgaris* L.	Common groundsel	C									
Caryophyllaceae	*Silene latifolia* Poir. ssp. *alba* (P. Mill.) Greuter & Burdet	Bladder campion	C	X	X							
Asteraceae	*Tanacetum vulgare* L.	Common tansy	C		X	X	X				X	X

Table 2—All other non-native plants on the Mt. Baker-Snoqualmie National Forest, by Ranger District and Washington State County. Species marked with an asterisk (*) are escaped or deliberately planted ornamentals

Family	Scientific Name	Common Name	Mt. Baker RD	Darrington RD	Skykomish RD	Snoqualmie RD	Whatcom County	Skagit County	Snohomish County	King County	Pierce County
Apiaceae	*Aegopodium podagraria* L.	Bishop's goutweed	X					X			
Poaceae	*Agrostis capillaris* L.	Colonial bentgrass	X	X		X	X	X	X	X	X
Poaceae	*Agrostis gigantea* Roth	Redtop			X	X				X	
Simaroubaceae	*Ailanthus altissima* (P. Mill.) Swingle*	Tree-of-heaven		X					X		
Poaceae	*Aira caryophyllea* L.	Silver hairgrass		X	X			X			
Lamiaceae	*Ajuga reptans* L.	Common bugle		X					X		
Poaceae	*Alopecurus geniculatus* L.	Water foxtail				X					X
Asteraceae	*Arctium lappa* L.	Greater burdock	X	X			X	X	X		
Asteraceae Bernh.	*Arctium minus*	Lesser burdock	X		X	X	X			X	X
Poaceae	*Arrhenatherum elatius* (L.) Beauv. ex J.& K. Presl	Tall oatgrass			X	X	X		X	X	X
Poaceae	*Avena fatua* L.	Wild oat		X					X		
Asteraceae	*Bellis perennis* L.	Lawndaisy	X				X	X			
Poaceae	*Bromus tectorum* L.	Cheatgrass				X					X
Poaceae	*Bromus inermis Leyss.* subsp. *inermis*	Smooth brome	X	X			X		X	X	
Convolvulaceae	*Calystegia sepium* (L.) R. Br.	False hedge bindweed	X			X		X		X	
Brassicaceae	*Capsella bursa-pastoris* (L.) Medik.	Shepherd's purse		X		X			X		X
Caryophyllaceae	*Cerastium fontanum* Baumg. ssp. *vulgare* (Hartman) Greuter & Burdet	Big chickweed	X	X		X	X			X	X
Caryophyllaceae	*Cerastium semidecandrum* L.	Fivestamen chickweed				X					X
Rosaceae	*Chaenomeles* sp.*	Flowering quince	X				X				
Liliaceae	*Convallaria majalis* L.*	Lily-of-the-valley	X			X	X				X
Rosaceae	*Crataegus monogyna* Jacq.*	Oneseed hawthorn		X		X			X	X	
Asteraceae	*Crepis capillaris* (L.) Wallr.	Smooth hawksbeard	X	X			X		X		
Poaceae	*Cynosurus cristatus* L.	Crested dogstail grass		X					X		
Poaceae	*Dactylis glomerata* L.	Orchardgrass	X	X	X	X	X	X	X	X	X

Table 2—All other non-native plants on the Mt. Baker-Snoqualmie National Forest, by Ranger District and Washington State County. Species marked with an asterisk (*) are escaped or deliberately planted ornamentals (continued)

Family	Scientific Name	Common Name	Mt. Baker RD	Darrington RD	Skykomish RD	Snoqualmie RD	Whatcom County	Skagit County	Snohomish County	King County	Pierce County
Caryophyllaceae	*Dianthus armeria* L.	Deptford pink				X				X	
Caryophyllaceae	*Dianthus deltoides* L.	Maiden pink			X					X	
Scrophulariaceae	*Digitalis purpurea* L.*	Foxglove	X	X	X	X	X	X	X	X	X
Brassicaceae	*Draba verna* L.	Spring draba	X				X				
Rosaceae	*Duchesnea indica* (Andr.) Focke*	Indian strawberry	X				X				
Poaceae	*Elymus repens* (L.) Gould	Quackgrass	X	X		X		X	X	X	
Geraniaceae	*Erodium cicutarium* (L.) L'Hér. ex Ait.	Stork's bill				X					X
Scrophulariaceae	*Euphrasia stricta* D. Wolff ex J.F. Lehm	Eyebright	X	X		X	X		X	X	X
Lamiaceae	*Galeopsis tetrahit* L.	Brittlestem hempnettle	X	X			X		X		
Rubiaceae	*Galium odoratum* (L.) Scop.*	Sweetscented bedstraw			X					X	
Geraniaceae	*Geranium dissectum* L.	Cutleaf geranium		X				X			
Geraniaceae	*Geranium molle* L.	Dovefoot geranium	X				X	X			
Lamiaceae	*Glechoma hederacea* L.*	Ground ivy	X	X	X		X	X		X	
Asteraceae	*Gnaphalium uliginosum* L.	Marsh cudweed	X				X				
Brassicaceae	*Hesperis matronalis* L.	Dame's rocket			X					X	
Poaceae	*Holcus lanatus* L.	Velvetgrass	X	X	X	X	X	X	X	X	X
Liliaceae	*Hosta* sp.*	Hosta				X				X	
Clusiaceae	*Hypericum calycinum* L.*	Aaron's beard	X				X				
Asteraceae	*Hypochaeris glabra* L.	Smooth catsear	X				X				
Aquifoliaceae	*Ilex aquifolium* L.*	English holly	X	X	X	X	X	X		X	
Asteraceae	*Lactuca serriola* L.	Prickly lettuce									
Lamiaceae	*Lamiastrum galeobdolon* (L.) Ehrend. & Polatschek*	Yellow archangel			X	X				X	
Lamiaceae	*Lamium amplexicaule* L.	Henbit deadnettle		X					X		
Asteraceae	*Lapsana communis* L.	Nipplewort	X		X	X	X		X	X	X
Fabaceae	*Lathyrus latifolius* L.*	Perennial pea				X					X
Lamiaceae	*Lavandula angustifolia**	Lavender		X		X				X	

Table 2—All other non-native plants on the Mt. Baker-Snoqualmie National Forest, by Ranger District and Washington State County. Species marked with an asterisk (*) are escaped or deliberately planted ornamentals (continued)

Family	Scientific Name	Common Name	Mt. Baker RD	Darrington RD	Skykomish RD	Snoqualmie RD	Whatcom County	Skagit County	Snohomish County	King County	Pierce County
Brassicaceae	*Lepidium perfoliatum* L.	Clasping pepperweed		X							
Poaceae	*Lolium perenne* L.	Perennial ryegrass	X	X			X	X	X		
Fabaceae	*Lotus corniculatus* L.	Bird's-foot trefoil	X	X	X	X	X	X	X	X	X
Malvaceae	*Malva moschata* L.*	Musk mallow				X				X	
Malvaceae	*Malva parviflora* L.	Cheeseweed				X					X
Asteraceae	*Matricaria discoidea* DC.	Mayweed	X		X	X	X	X		X	X
Fabaceae	*Medicago lupulina* L.	Black medic	X	X	X	X	X	X	X	X	
Fabaceae	*Melilotus officinalis* (L.) Lam.	White sweetclover	X		X	X	X	X	X	X	X
Asteraceae	*Mycelis muralis* (L.) Dumort.	Wall lettuce	X	X	X	X	X	X	X	X	X
Asteraceae	*Myosotis arvensis* (L.) Hill	Field forget-me-not	X				X				
Boraginaceae	*Myosotis scorpioides* L.	True forget-me-not	X			X	X			X	X
Boraginaceae	*Myosotis sylvatica* Ehrh. ex Hoffmann	Woodland forget-me -not			X					X	
Liliaceae	*Narcissus* sp.*	Daffodil				X				X	
Brassicaceae	*Nasturtium officinale* Ait. f.	Watercress	X				X	X			
Asteraceae	*Petasites japonicus* (Siebold & Zucc.) Maxim. subsp. *giganteus* (F. Schmidt ex Trautv.) Kitam.*	Japanese butterbur	X				X				
Poaceae	*Phleum pratense* L.	Timothy	X	X	X	X	X	X	X	X	X
Plantaginaceae	*Plantago lanceolata* L.	English plantain	X	X	X	X	X	X	X	X	X
Plantaginaceae	*Plantago major* L.	Common plantain	X	X	X	X	X	X	X	X	X
Poaceae	*Poa annua* L.	Annual bluegrass	X	X	X	X	X		X	X	X
Poaceae	*Poa bulbosa* L.	Bulbous bluegrass				X					X
Poaceae	*Poa compressa* L.	Canada bluegrass		X	X				X		
Poaceae	*Poa trivialis* L.	Rough bluegrass			X				X		
Poaceae	*Polypogon monspeliensis* (L.) Desf	annual rabbitsfoot grass.				X					X
Rosaceae	*Prunus laurocerasus* L.*	Cherry laurel	X				X				
Ranunculaceae	*Ranunculus acris* L.	Tall buttercup		X		X			X		X
Ranunculaceae	*Ranunculus repens* L.	Creeping buttercup	X	X	X	X	X	X	X	X	X
Polygonaceae	*Rheum rhabarbarum* L.*	Rhubarb				X				X	
Ericaceae	*Rhododendron* sp.*	Rhododendron	X			X	X	X			X

Table 2—All other non-native plants on the Mt. Baker-Snoqualmie National Forest, by Ranger District and Washington State County. Species marked with an asterisk (*) are escaped or deliberately planted ornamentals (continued)

Family	Scientific Name	Common Name	Mt. Baker RD	Darrington RD	Skykomish RD	Snoqualmie RD	Whatcom County	Skagit County	Snohomish County	King County	Pierce County
Lamiaceae	*Rosmarinus officinalis* L.*	Rosemary				X				X	
Polygonaceae	*Rumex acetosella* L.	Sheep sorrel	X	X	X	X	X	X	X	X	X
Polygonaceae	*Rumex crispus* L.	Curly dock	X	X	X	X	X	X	X	X	X
Polygonaceae	*Rumex obtusifolius* L.	Bitter dock	X	X	X	X	X	X		X	X
Caryophyllaceae	*Sagina apetala* Ard.	Annual pearlwort				X					X
Caryophyllaceae	*Sagina procumbens* L.	Birdeye pearlwort		X		X			X		X
Poaceae	*Schedonorus pratensis* (Huds.) Beauv.	Meadow fescue	X			X	X	X		X	X
Poaceae	*Schedonorus phoenix* (Scop.) Holub	Tall fescue	X	X		X		X	X	X	X
Asteraceae	*Senecio sylvaticus* L.	Woodland groundsel	X	X	X	X	X		X	X	
Solanaceae	*Solanum dulcamara* L.	Bitter nightshade	X	X	X	X	X		X	X	
Asteraceae	*Sonchus asper* (L.) Hill	Spiny sowthistle	X	X	X		X		X	X	
Asteraceae	*Sonchus oleraceus* L.	Common sowthistle				X				X	
Rosaceae	*Sorbus aucuparia* L.*	European mountain ash	X			X	X	X		X	
Caryophyllaceae	*Spergularia rubra* (L.) J.& K. Presl	Red sandspurry				X					X
Lamiaceae	*Stachys byzantina* K. Koch*	Lamb's ears				X				X	
Caryophyllaceae	*Stellaria media* (L.) Vill.	Common chickweed	X			X				X	X
Boraginaceae	*Symphytum officinale* L.*	Comfrey	X			X	X			X	
Asteraceae	*Taraxacum laevigatum* (Willd.) DC.	Rock dandelion	X				X				
Asteraceae	*Taraxacum officinale* G.H. Weber ex. Wiggers	Dandelion	X	X	X	X	X	X	X	X	X
Asteraceae	*Tragopogon dubius* Scop.	Yellow salsify	X			X				X	X
Fabaceae	*Trifolium arvense* L.	Rabbitfoot clover	X			X	X			X	X
Fabaceae	*Trifolium campestre* Schreb.	Field clover	X				X				
Fabaceae	*Trifolium dubium* Sibthorp	Suckling clover	X	X		X	X	X	X	X	X
Fabaceae	*Trifolium hybridum* L.	Alsike clover	X		X	X	X	X	X	X	X
Fabaceae	*Trifolium pratense* L.	Red clover	X	X	X	X	X	X	X		X
Fabaceae	*Trifolium repens* L.	White clover	X	X	X	X	X	X	X	X	X

Table 2—All other non-native plants on the Mt. Baker-Snoqualmie National Forest, by Ranger District and Washington State County. Species marked with an asterisk (*) are escaped or deliberately planted ornamentals (continued)

Family	Scientific Name	Common Name	Mt. Baker RD	Darrington RD	Skykomish RD	Snoqualmie RD	Whatcom County	Skagit County	Snohomish County	King County	Pierce County
Caryophyllaceae	*Vaccaria segetalis* (P. Mill.) Rauschert	Cow soapwort			X					X	
Scrophulariaceae	*Verbascum thapsus* L.	Common mullein	X	X	X	X		X	X	X	X
Scrophulariaceae	*Veronica arvensis* L.	Corn speedwell	X			X	X				
Asteraceae	*Tragopogon dubius* Scop.	Yellow salsify	X			X				X	X
Scrophulariaceae	*Veronica chamaedrys* L.	Germander speedwell	X	X	X	X	X	X	X	X	X
Scrophulariaceae	*Veronica officinalis* L.	Common gypsyweed	X	X		X	X	X	X	X	X
Scrophulariaceae	*Veronica persica* Poir.	Birdeye speedwell				X				X	
Fabaceae	*Vicia cracca* L.	Bird vetch				X				X	
Fabaceae	*Vicia sativa* L.	Garden vetch	X		X	X	X			X	
Apocynaceae	*Vinca minor* L.*	Common periwinkle	X			X	X			X	
Poaceae	*Vulpia bromoides* (L.) S.F. Gray	Brome fescue	X				X				

Table 3—Updated nomenclature of all non-native plants known to occur on the Mt. Baker-Snoqualmie National Forest compared with the Pacific Northwest regional flora (Hitchcock and Cronquist 1973). All accepted scientific names follow the PLANTS database (USDA Natural Resources Conservation Service 2006)

Accepted Scientific Name	In PNW flora?	Synonym Used in PNW flora
Aegopodium podagraria		
Agrostis capillaris	X	*Agrostis tenuis*
Agrostis gigantea	X	
Ailanthus altissima	X	
Aira caryophyllea	X	
Ajuga reptans	X	
Alopecurus geniculatus	X	
Arctium lappa	X	
Arctium minus	X	
Arrhenatherum elatius	X	
Avena fatua	X	
Bellis perennis	X	
Bromus tectorum	X	
Buddleja davidii	X	
Calystegia sepium	X	*Convolvulus sepium*
Capsella bursa-pastoris	X	
Centaurea ×moncktonii	X	*Centaurea pratensis*
Centaurea biebersteinii	X	*Centaurea maculosa*
Centaurea diffusa	X	
Cerastium fontanum ssp. *vulgare*	X	*Cerastium vulgatum*
Cerastium semidecandrum	X	
Cirsium arvense	X	
Cirsium vulgare	X	
Conium maculatum	X	
Convallaria majalis		
Convolvulus arvensis	X	
Crataegus monogyna	X	*C. monogyna* and *C. oxyacantha*
Crepis capillaris	X	
Cynosurus cristatus	X	
Cytisus scoparius	X	
Dactylis glomerata	X	
Daucus carota	X	
Dianthus armeria	X	
Dianthus deltoides	X	
Digitalis purpurea	X	
Draba verna	X	
Duchesnea indica	X	
Elymus repens	X	*Agropyron repens*
Erodium cicutarium	X	
Euphrasia stricta	X	*Euphrasia officinalis*
Galeopsis tetrahit	X	
Galium odoratum	X	*Asperula odorata*
Geranium dissectum	X	
Geranium molle	X	
Geranium robertianum	X	
Glechoma hederacea	X	
Gnaphalium uliginosum	X	

Table 3—Updated nomenclature of all non-native plants known to occur on the Mt. Baker-Snoqualmie National Forest compared with the Pacific Northwest regional flora (Hitchcock and Cronquist 1973). All accepted scientific names follow the PLANTS database (USDA Natural Resources Conservation Service 2006) (continued)

Accepted Scientific Name	In PNW flora?	Synonym Used in PNW flora
Hedera helix	X	
Heracleum mantegazzianum		
Hesperis matronalis	X	
Hieracium aurantiacum	X	
Hieracium caespitosum	X	*Hieracium pratense*
Hieracium lachenalii	X	*Hieracium vulgatum*
Hieracium laevigatum		
Holcus lanatus	X	
Hosta sp.		
Hypericum calycinum		
Hypericum perforatum	X	
Hypochaeris glabra	X	
Hypochaeris radicata	X	
Ilex aquifolium		
Impatiens glandulifera	X	
Lactuca serriola	X	
Lamiastrum galeobdolon		
Lamium amplexicaule	X	
Lapsana communis	X	
Lathyrus latifolius	X	
Lavandula angustifolia		
Lepidium perfoliatum	X	
Leucanthemum vulgare	X	*Chrysanthemum leucanthemum*
Linaria dalmatica	X	
Linaria genistifolia	X	
Linaria vulgaris	X	
Lolium perenne	X	
Lotus corniculatus	X	
Lychnis coronaria	X	
Malva moschata	X	
Malva parviflora	X	
Matricaria discoidea	X	*Matricaria matricariodes*
Medicago lupulina	X	
Melilotus officinalis	X	*M. officinalis* and *M. alba*
Mycelis muralis	X	*Lactuca muralis*
Myosotis arvensis	X	
Myosotis scorpioides	X	
Narcissus sp.		
Nasturtium officinale	X	*Rorippa nasturtium-aquaticum*
Petasites japonicus subsp. *giganteus*		
Phalaris arundinacea	X	
Phleum pratense	X	
Plantago lanceolata	X	
Plantago major	X	
Poa annua	X	
Poa bulbosa	X	
Poa compressa	X	

Table 3—Updated nomenclature of all non-native plants known to occur on the Mt. Baker-Snoqualmie National Forest compared with the Pacific Northwest regional flora (Hitchcock and Cronquist 1973). All accepted scientific names follow the PLANTS database (USDA Natural Resources Conservation Service 2006) (continued)

Accepted Scientific Name	In PNW flora?	Synonym Used in PNW flora
Poa trivialis	X	
Polygonum cuspidatum	X	
Polygonum sachalinense	X	
Polygonum × *bohemicum*		
Polypogon monspeliensis	X	
Potentilla recta	X	
Prunus laurocerasus	X	
Ranunculus acris	X	
Ranunculus repens	X	
Rheum rhabarbarum		
Rhododendron sp.		
Rosmarinus officinalis		
Rubus armeniacus	X	*Rubus discolor*
Rubus laciniatus	X	
Rumex acetosella	X	
Rumex crispus	X	
Rumex obtusifolius	X	
Sagina apetala	X	
Sagina procumbens	X	
Schedonorus pratensis	X	*Festuca pratensis*
Schedonorus phoenix	X	*Festuca arundinacea*
Senecio jacobaea	X	
Senecio sylvaticus	X	
Senecio vulgaris	X	
Silene latifolia ssp. *alba*	X	*Lychnis alba*
Silene noctiflora	X	
Solanum dulcamara	X	
Sonchus asper	X	
Sonchus oleraceus	X	
Sorbus aucuparia	X	
Spergula arvensis	X	
Spergularia rubra	X	
Stachys byzantina		
Stellaria media	X	
Symphytum officinale	X	
Tanacetum vulgare	X	
Taraxacum laevigatum	X	
Taraxacum officinale	X	
Tragopogon dubius	X	
Trifolium arvense	X	
Trifolium campestre	X	*Trifolium procumbens*
Trifolium dubium	X	
Trifolium hybridum	X	
Trifolium pratense	X	
Trifolium repens	X	
Vaccaria segetalis	X	
Verbascum thapsus	X	

Table 3—Updated nomenclature of all non-native plants known to occur on the Mt. Baker-Snoqualmie National Forest compared with the Pacific Northwest regional flora (Hitchcock and Cronquist 1973). All accepted scientific names follow the PLANTS database (USDA Natural Resources Conservation Service 2006) (continued)

Accepted Scientific Name	In PNW flora?	Synonym Used in PNW flora
Veronica arvensis	X	
Veronica chamaedrys	X	
Veronica officinalis	X	
Veronica persica	X	
Vicia cracca	X	
Vicia sativa	X	
Vinca minor		
Vulpia bromoides	X	*Festuca bromoides*

Table 4—Comparison of the ecology plot and botany survey detections of noxious weeds table 1) and other non-native plants (table 2) known to occur on the Mt. Baker-Snoqualmie National Forest

Family	Scientific Name	Noxious Weed	# detections Ecology	# detections Botany
Apiaceae	*Aegopodium podagraria*		0	1
Apiaceae	*Conium maculatum*		0	1
Apiaceae	*Daucus carota*		0	3
Apiaceae	*Heracleum mantegazzianum*	X	0	0
Apocynaceae	*Vinca minor*		0	3
Aquifoliaceae	*Ilex aquifolium*		5	4
Araliaceae	*Hedera helix*	X	0	2
Asteraceae	*Arctium lappa*		0	4
Asteraceae	*Arctium minus*		2	5
Asteraceae	*Bellis perennis*		0	2
Asteraceae	*Centaurea biebersteinii*	X	0	7
Asteraceae	*Centaurea diffusa*	X	0	2
Asteraceae	*Centaurea* × *moncktonii*	X	0	0
Asteraceae	*Cirsium arvense*	X	14	87
Asteraceae	*Cirsium vulgare*	X	18	72
Asteraceae	*Crepis capillaris*		0	8
Asteraceae	*Gnaphalium uliginosum*		0	1
Asteraceae	*Hieracium aurantiacum*	X	0	21
Asteraceae	*Hieracium caespitosum*	X	0	2
Asteraceae	*Hieracium lachenalii*	X	0	1
Asteraceae	*Hypochaeris glabra*		0	1
Asteraceae	*Hypochaeris radicata*	X	13	144
Asteraceae	*Lactuca serriola*		0	0
Asteraceae	*Lapsana communis*		1	32
Asteraceae	*Leucanthemum vulgare*	X	7	230
Asteraceae	*Matricaria discoidea*		0	24
Asteraceae	*Mycelis muralis*		439	422
Asteraceae	*Petasites japonicus* subsp. *giganteus*		0	1
Asteraceae	*Senecio jacobaea*	X	1	22
Asteraceae	*Senecio sylvaticus*		6	5
Asteraceae	*Senecio vulgaris*	X	0	5

Table 4—Comparison of the ecology plot and botany survey detections of noxious weeds (table 1) and other non-native plants (table 2) known to occur on the Mt. Baker-Snoqualmie National Forest (continued)

Family	Scientific Name	Noxious Weed	# detections Ecology	# detections Botany
Asteraceae	*Sonchus asper*		0	4
Asteraceae	*Sonchus oleraceus*		0	3
Asteraceae	*Tanacetum vulgare*	X	1	66
Asteraceae	*Taraxacum laevigatum*		0	1
Asteraceae	*Taraxacum officinale*		3	115
Asteraceae	*Tragopogon dubius*		0	10
Balsaminaceae	*Impatiens glandulifera*	X	0	0
Boraginaceae	*Myosotis arvensis*		0	1
Boraginaceae	*Myosotis scorpioides*		0	2
Boraginaceae	*Symphytum officianale*		0	1
Brassicaceae	*Capsella bursa-pastoris*		0	6
Brassicaceae	*Draba verna*		0	1
Brassicaceae	*Hesperis matronalis*		0	1
Brassicaceae	*Lepidium perfoliatum*		0	1
Brassicaceae	*Nasturtium officinale*		0	1
Buddlejaceae	*Buddleja davidii*	X	0	1
Caryophyllaceae	*Cerastium fontanum* ssp. *vulgare*		0	14
Caryophyllaceae	*Cerastium semidecandrum*		0	1
Caryophyllaceae	*Dianthus armeria*		0	2
Caryophyllaceae	*Dianthus deltoides*		0	1
Caryophyllaceae	*Lychnis coronaria*		0	1
Caryophyllaceae	*Sagina apetala*		0	1
Caryophyllaceae	*Sagina procumbens*		0	8
Caryophyllaceae	*Silene latifolia* ssp. *alba*	X	1	5
Caryophyllaceae	*Silene noctiflora*		0	2
Caryophyllaceae	*Spergula arvensis*		0	1
Caryophyllaceae	*Spergularia rubra*		0	7
Caryophyllaceae	*Stellaria media*		1	6
Caryophyllaceae	*Vaccaria segetalis*		0	1
Clusiaceae	*Hypericum calycinum*		0	1
Clusiaceae	*Hypericum perforatum*	X	7	176
Convolvulaceae	*Calystegia sepium*		0	1
Convolvulaceae	*Convolvulus arvensis*	X	0	1
Ericaceae	*Rhododendron* sp.		0	1
Fabaceae	*Cytisus scoparius*	X	0	35
Fabaceae	*Lathyrus latifolius*		0	4
Fabaceae	*Lotus corniculatus*		1	57
Fabaceae	*Lotus pinnatus*		0	1
Fabaceae	*Medicago lupulina*		0	15
Fabaceae	*Melilotus officinalis*		0	10
Fabaceae	*Trifolium arvense*		0	2
Fabaceae	*Trifolium campestre*		0	
Fabaceae	*Trifolium dubium*		0	6
Fabaceae	*Trifolium hybridum*		0	9
Fabaceae	*Trifolium pratense*		0	79
Fabaceae	*Trifolium repens*		10	173
Fabaceae	*Vicia cracca*		1	0

Table 4—Comparison of the ecology plot and botany survey detections of noxious weeds (table 1) and other non-native plants (table 2) known to occur on the Mt. Baker-Snoqualmie National Forest (continued)

Family	Scientific Name	Noxious Weed	# detections Ecology	Botany
Fabaceae	*Vicia sativa*		1	3
Geraniaceae	*Erodium cicutarium*		0	1
Geraniaceae	*Geranium dissectum*		0	1
Geraniaceae	*Geranium molle*		0	2
Geraniaceae	*Geranium robertianum*	X	1	69
Lamiaceae	*Ajuga reptans*		0	2
Lamiaceae	*Galeopsis tetrahit*		1	7
Lamiaceae	*Glechoma hederacea*		0	3
Lamiaceae	*Lamiastrum galeobdolon*		0	1
Lamiaceae	*Lamium amplexicaule*		1	1
Lamiaceae	*Lamium maculatum*		1	0
Lamiaceae	*Lavandula angustifolia*		0	1
Lamiaceae	*Rosmarinus officinalis*		0	1
Lamiaceae	*Stachys byzantina*		0	0
Liliaceae	*Convallaria majalis*		0	2
Liliaceae	*Hosta* sp.		0	1
Liliaceae	*Narcissus* sp.		0	1
Malvaceae	*Malva moschata*		0	0
Malvaceae	*Malva parviflora*		0	2
Plantaginaceae	*Plantago lanceolata*		1	153
Plantaginaceae	*Plantago major*		0	191
Poaceae	*Agrostis capillaris*		7	9
Poaceae	*Agrostis gigantea*		0	4
Poaceae	*Aira caryophyllea*		2	1
Poaceae	*Alopecurus geniculatus*		0	5
Poaceae	*Arrhenatherum elatius*		0	8
Poaceae	*Avena fatua*		0	1
Poaceae	*Bromus tectorum*		0	0
Poaceae	*Cynosurus cristatus*		0	1
Poaceae	*Dactylis glomerata*		12	195
Poaceae	*Elymus repens*		0	6
Poaceae	*Holcus lanatus*		12	41
Poaceae	*Lolium perenne*		0	9
Poaceae	*Phalaris arundinacea*	X	0	107
Poaceae	*Phleum pratense*		13	105
Poaceae	*Poa annua*		0	23
Poaceae	*Poa bulbosa*		0	1
Poaceae	*Poa compressa*		0	2
Poaceae	*Poa trivialis*		1	1
Poaceae	*Polypogon monspeliensis*		0	1
Poaceae	*Schedonorus pratensis*		1	3
Poaceae	*Schedonorus phoenix*		3	12
Poaceae	*Vulpia bromoides*		0	1
Polygonaceae	*Polygonum cuspidatum*	X	0	3
Polygonaceae	*Polygonum sachalinense*	X	0	2
Polygonaceae	*Polygonum × bohemicum*	X	0	0
Polygonaceae	*Rheum rhabarbarum*		0	0

Table 4—Comparison of the ecology plot and botany survey detections of noxious weeds (table 1) and other non-native plants (table 2) known to occur on the Mt. Baker-Snoqualmie National Forest (continued)

Family	Scientific Name	Noxious Weed	# detections Ecology	# detections Botany
Polygonaceae	*Rumex acetosella*		8	106
Polygonaceae	*Rumex crispus*		0	59
Polygonaceae	*Rumex obtusifolius*		2	24
Ranunculaceae	*Ranunculus acris*		0	15
Ranunculaceae	*Ranunculus repens*		11	246
Rosaceae	*Crataegus monogyna*		0	1
Rosaceae	*Duchesnea indica*		0	1
Rosaceae	*Potentilla recta*	X	0	1
Rosaceae	*Prunus laurocerasus*		0	1
Rosaceae	*Rubus armeniacus*	X	2	35
Rosaceae	*Rubus laciniatus*	X	9	65
Rosaceae	*Sorbus aucuparia*		1	8
Rubiaceae	*Galium odoratum*		0	1
Scrophulariaceae	*Digitalis purpurea*		29	160
Scrophulariaceae	*Euphrasia stricta*		0	26
Scrophulariaceae	*Linaria dalmatica*	X	0	4
Scrophulariaceae	*Linaria genistifolia*		0	1
Scrophulariaceae	*Linaria vulgaris*		0	1
Scrophulariaceae	*Verbascum thapsus*		2	26
Scrophulariaceae	*Veronica arvensis*		2	4
Scrophulariaceae	*Veronica chamaedrys*		11	11
Scrophulariaceae	*Veronica officinalis*		0	70
Scrophulariaceae	*Veronica persica*		0	2
Simaroubaceae	*Ailanthus altissima*		0	1
Solanaceae	*Solanum dulcamara*		3	4

Table 5—Summary of detection rates of non-native vascular plants and comparison of botany surveys and ecology plots

		Ecology Plots	Botany Surveys
# of Detections	Noxious Weeds	74	1165
	Other Non-native Plants	594	2299
	All Non-Native Plants	668	3464
# Species Detected	Noxious Weeds	13	25
	Other Non-native Plants	30	112
	All Non-Native Plants	43	139
Percent of Species Detected	All Known Noxious Weeds on Forest	38	74
	All Other Known Non-native Plants	26	98
	All Known Non-native Plants	29	94

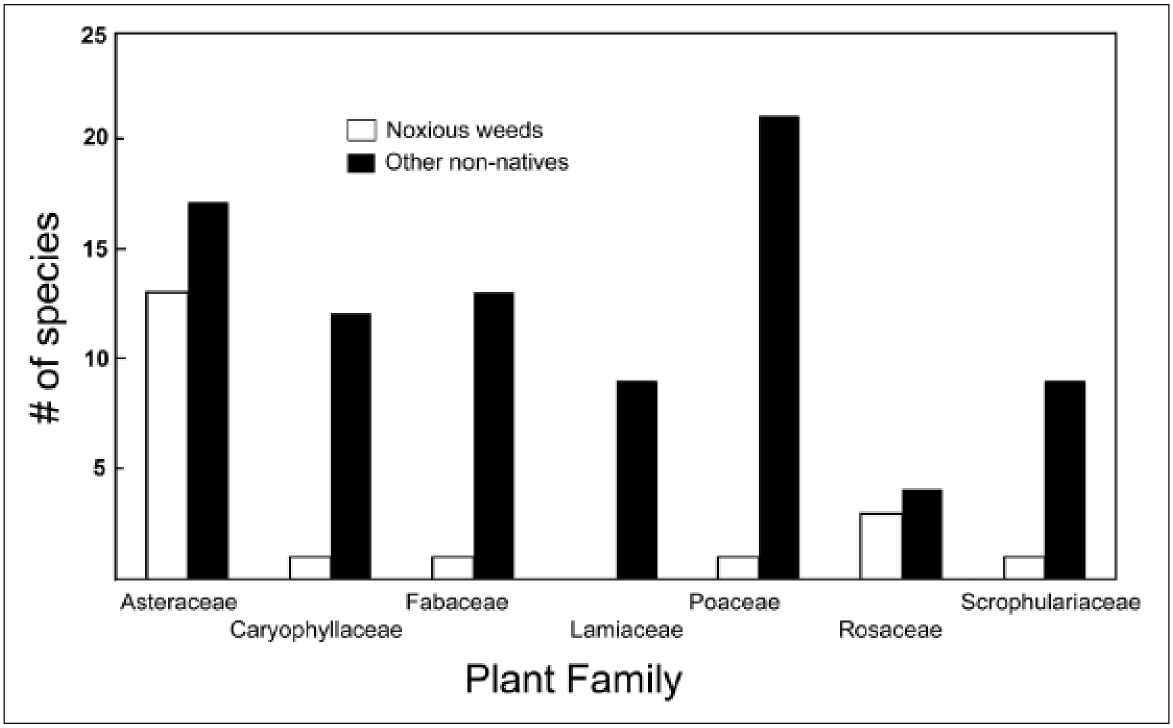

Figure 2—Plant families with the greatest number of noxious weeds and other non-native plants on the Mt. Baker-Snoqualmie National Forest.

reviewed our list of noxious weeds known to occur on the Forest, wondered at the omission of *I. glandulifera*, and then informed us that he had recently collected it on the Darrington Ranger District, Snohomish County (David Giblin, University of Washington Herbarium, pers. comm).

Although we knew that noxious weeds and other non-native plants are present in all four ranger districts and five counties, we did not expect so many ornamental plants not listed as noxious weeds to be present on the Forest (table 2).

Until September 2005, none of us had ever seen *Lamiastrum galeobdolon* (L.) Ehrend. & Polatschek, a shade tolerant ground cover on the Forest, until one of us (Fuentes) discovered it near the Denny Creek trailhead on the Snoqualmie Ranger District (King County). We later discovered that it was rapidly spreading in Seattle's city parks (Wendy Descamp, University of Washington Botanical Gardens, pers. comm) and that the King County Noxious Weed Board was proposing that it be listed as a state noxious weed (Steven Burke, King County Noxious Weed Board, pers. comm). We have since documented it on three more sites on the Forest.

Limiting disturbance and maintaining canopy cover to provide shade are part of the Forest's prevention strategy (USDA Forest Service 2005). However, this assumes that invasive plants cannot invade intact plant communities and are shade intolerant. Because sites of *L. galeobdolon* and *G. robertianum* are in deep to dappled shade, it would appear that much more of the Forest is vulnerable to invasion by such shade tolerant species.

Sources of establishment and spread

Because noxious weeds on the Forest tend to be associated with highways and roads, trails, railroad tracks, and power-line corridors, we infer that: 1) noxious weeds and other non-native plants spread themselves along these constantly disturbed areas, and that 2) vehicles of visitors to the Forest may contain seeds or other propagules.

In addition to inadvertently spreading non-natives, Forest visitors are also directly spreading non-native species on the Forest by planting ornamentals or dumping yard waste. Botanists have noted deliberate plantings of *Hypericum calcyinum* L., *Prunus laurocerasus* L., *Narcissus* sp., *Hosta* sp., ornamental *Rhododendron* spp., *Rosmarinus officinalis* L.; they have also observed L. *galeobdolon, Hedera helix* L., *Symphytum officinale* L., *Rheum rhabarbarum* L., *Vinca minor* L., and *G. robertianum* growing in or adjacent to debris piles along Forest System roads.

The use of rock, gravel, and fill that contain seeds and other plant parts has also contributed to the spread and establishment of noxious weeds on the Forest. For example, *P.* × *bohemicum* occurs in and around riprap by the Johnson Creek bridge in Snohomish County on the Skykomish Ranger District. Because no other infestations of this species are known from the reach above the bridge or along the road to or from it, it is likely that the riprap contained pieces of *P.* × *bohemicum*. Forest engineering records state that the riprap was used as part of the Johnson Creek bridge replacement in 1998.

Major floods may also contribute to the spread of invasive *Polygonum* spp. on the Forest. Results from repeat surveys of the Sauk River suggest that new infestations may begin when entire plants, rhizomes, or other parts break off and are carried downstream. Five of the nine infestations known from the upper Sauk River were washed away by floods in 2003 (Melisa Holman, The Nature Conservancy, pers. comm). About 200 new patches were identified in previously uninfested areas downstream from the swept away infestations.

Floodwaters are not the only way that invasive *Polygonum* spp. are suspected to move within the floodplain. A contractor working on weed control on the Darrington Ranger District reported that mountain beaver (*Aplodontia rufa* Rafinesque) have cut down stems of *P.* × *bohemicum* and dragged them back to their burrows.

Within the past 10 years, the Forest has acquired several new parcels of land. Unfortunately, many of these are infested with invasive plants. The SkiYou parcel, on the Mt. Baker Ranger District, is in Skagit County along the Skagit River. This parcel contains *Rubus armeniacus* Focke, *P.* × *bohemicum*, *Tanacetum vulgare* L., *B. davidii*, *C. arvense*, and *C. vulgare*. The Snoqualmie Point parcel, on the Snoqualmie Ranger District, is in King County, along the I-90 corridor. Not only does this parcel contain all of the same species as the SkiYou parcel, it also contains *Rubus laciniatus* Willd., *S. jacobaea*, *H. helix*, *G. robertianum*, and *Ilex aquifolium* L.

Differences in detection

Because botany surveys often occur in areas associated with roads and trails and that survey areas are typically larger than ecology plots (table 4), it is not surprising that botany surveys detected a higher proportion of non-native plants, including noxious weeds. Botany surveys target specific areas, rare species, and non-native plants, while ecology plot surveys represent a sample of the Forest vegetation.

Given that controlling non-native plants is more likely to be feasible and economical when infestations are small (Rejmánek and Pitcairn 2002, Simberloff 2003), detecting new infestations soon after they occur is crucial. Sampling schemes for detecting rare species and events are applicable to this effort.

Cutler et al. (2001) reviewed different sampling schemes for detecting rare events, grouped them into five categories, and commented on their relevance for detecting rare or uncommon Survey and Manage Species in Pacific Northwest forests. We apply his same groupings and comment on their relevance for detecting new infestations of non-native plants on the Forest.

<u>Collecting a very large sample.</u> When little is known about the species of interest, then this approach can be a starting point. However, it can be extremely expensive. The Forest already has two large, high-quality, long-term data sets regarding the distribution of vascular plants on the Forest: the botany survey and ecology plot databases. Developing new schemes to detect non-natives would be redundant and expensive.

<u>Stratified random sampling with disproportionate allocation.</u> If the Forest could predict where non-native plants are more likely to be found, then botanists and ecologists could focus their efforts in these areas. Because we know that most noxious weed sites on the Forest occur along roads, trails, and other disturbed, accessible areas, and because we understand many of the mechanisms that contribute to the spread and establishment of noxious weeds, focusing our efforts in these areas would likely result in higher detection rates.

However, the reproductive biology and habitat tolerances of all of the possible non-native species are not well understood, and it is possible that we will miss certain species if we have too narrow a focus. If we only examined roads and trails, for example, we would miss many of the riparian weed infestations.

Snowball or network sampling. This method assumes that members of the population are linked. Finding one member of the population increases the likelihood of finding another. Indeed, many sites of non-native plants on the Forest contain two or more non-natives or may result from the same source (infested materials used all along a road, for example). Expanding our search radius around known sites of invasive plants of concern or following potential travel routes from one infestation would likely result in more detections. We may still, however, miss non-native plant sites that are not "linked" in some way to the existing populations.

Sequential methods. These methods involve developing an initial sampling scheme that is then used to determine an appropriate sampling scheme for the species of interest. This approach would involve taking our existing data sets, focusing on the species of interest, and selecting new areas to survey based on surrounding detection rates.

Model-based sampling. This scheme uses specific information about the species of interest to develop sample units with different probabilities of presence or absence. We (ecologists) have used this method with considerable success to detect rare and uncommon lichens (Lesher 2005), bryophytes, and vascular plants on the Forest (unpublished data). Developing these models has been time consuming and expensive.

However, determining areas that are vulnerable to a newly invading species is a high priority. Using information from the few known sites to predict where else these new invaders might occur would help focus our survey efforts for these species.

CONCLUSIONS

Non-native plants are widely distributed on the Forest, and complete eradication will never be feasible. The most effective ways to limit the harmful effects of invasive plants on the Forest are preventing their spread and establishment and identifying and controlling high priority infestations.

Our work shows that multiple approaches to identifying invasive plant infestations are necessary. Botany surveys tend to be tied to specific project areas; survey results can be used to help project managers prevent the spread and establishment of invasive plants. Ecology plots capture a representative sample of Forest vegetation changes, away from the influence of roads and trails. Prompt reporting of infestations by knowledgeable persons increases the likelihood of limiting invasive plants.

One of the Forest's highest priorities is controlling species not widely distributed on the Forest. Managers need to know which invasive plants are possible threats to Forest resources, as well as how and where these species may establish. Developing specific sampling schemes for specific, high priority invaders may be necessary. Network sampling or model-based sampling could be appropriate approaches.

However, recognizing new invaders and high priority infestations will be a continuing challenge. Professional knowledge of the flora of the Forest must be combined with a healthy suspicion of unfamiliar species. Skepticism should increase if the species is located near roads or trails, is unusually robust, or has ornamental plant characteristics, such as unusual textures, showy flowers, or variegated leaves.

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IS THE SPREAD OF NON-NATIVE PLANTS IN ALASKA ACCELERATING?

Matthew L. Carlson[1] and Michael Shephard[2]

ABSTRACT

Alaska has remained relatively unaffected by non-native plants; however, recently the state has started to experience an influx of invasive non-native plants that the rest of the U.S. underwent 60–100 years ago. With the increase in population, gardening, development, and commerce there have been more frequent introductions to Alaska. Many of these species, such as meadow hawkweed (*Hieracium caespitosum*), Canada thistle (*Cirsium arvense*), and spotted knapweed (*Centaurea biebersteinii*), have only localized populations in Alaska. Other species such as reed canary grass (*Phalaris arundinacea*) and white sweetclover (*Melilotus officinalis*), both formerly used in roadside seed mixes, are now very widespread and are moving into riparian areas and wetlands. We review the available literature and Alaska's statewide invasive plant database (AKEPIC, Alaska Exotic Plant Clearinghouse) to summarize changes in Alaska's non-native flora over the last 65 years. We suggest that Alaska is not immune to invasion, but rather that the exponential increase in non-native plants experienced elsewhere is delayed by a half century. This review highlights the need for more intensive detection and rapid response work if Alaska is going to remain free of many of the invasive species problems that plague the contiguous U.S.

KEYWORDS: Alaska, invasion patterns, invasive plants, non-native plants, plant databases.

INTRODUCTION

Most botanists and ecologists thought Alaska was immune to the invasion of non-native plants the rest of the United States had experienced, and continue to experience, given the great distances from source populations, relative lack of agriculture, low levels of human disturbance, and cold climates. Non-native plants are well known to compose significant components of all the other states' floras and biomass. Their presence as naturalized members of most communities is generally accepted; however, numerous non-native species are recognized for serious ecological and economic damage and targeted for control. Habitats in Alaska are extremely unique in this regard, being nearly free from the presence of non-native plants. Recently, however, populations of many non-native species appear to be expanding and most troubling, a number of species are spreading into natural habitats. The same fate of degraded ecological communities, damaged ecosystem function, endangerment of rare species, and lost economic revenue may be at the doorstep of the 49th state.

The process of species introductions and establishment are quite varied and complex (Pimm 1991, D'Antonio 1993, Williamson 1996) and, despite our fragmented understanding, it informs our comprehension of patterns in Alaska. In general, only a small proportion of total introductions results in the establishment of self-sustaining populations, a smaller proportion expands into natural areas,

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and an even smaller proportion causes significant ecological damage (the familiar Ten's Rule, Williamson 1996). The reasons why an introduction fails may be due to the plant's inability to tolerate the new physical and ecological conditions or because of stochastic events. Short summers, cold winters, and permafrost dominated habitats, among other things, clearly preclude many temperate species from establishing in Alaska. However, successful introductions are known to occur beyond species' expected climatic zones. Plants from temperate Europe have established as far north as 78º N in Svalbard, for example (Elven and Elvebakk 1996). The frequency and size of introductions (i.e., propagule pressure) is well-accepted to be a primary determinant of the success of introductions (Colautti et al. 2006). Low propagule pressure is likely one of the major reasons why Alaska has remained relatively free from non-native plants.

Once populations have been established they generally persist for some time without dramatic growth (i.e., lag phase) and are very susceptible to local extirpation. As population sizes begin to grow they may enter a more dramatic phase of increase (i.e., exponential growth phase; cf. Kinlan and Hastings 2005). Numerous cases, such as purple loosestrife (*Lythrum salicaria* L.) in the Midwest and starlings (*Sturnus vulgaris* L.) in New York, illustrate that a non-native species may appear to be relatively benign and restricted to a few small populations for many decades before expanding dramatically.

Here we review changes in the non-native flora of Alaska since the publication of the state's first flora in 1941 (Hultén 1941). Specifically, we explore whether species of non-natives are entering exponential growth phases, if species considered invasive differ in population expansion from non-natives as a whole, and what the geographic patterns of non-native establishment have been.

Historic background

Between 1941 and 1950 Eric Hultén published the first comprehensive flora of Alaska, which in many cases included non-native species and discussions of their origins. In 1968 the single volume, *Flora of Alaska and Neighboring Territories*, was published (Hultén 1968), and in it Hultén reported he used over three times the source material than in the earlier volumes. We use these pioneering and comprehensive works as a baseline to gauge changes in the region's non-native flora.

More recently federal and state agencies in Alaska have initiated non-native plant surveys to develop an understanding of the scope of the problem. In 1997 the USDA Forest Service began conducting surveys (Duffy 2003) and in 2000 the National Park Service launched basic inventory work (Densmore et al. 2001). Likewise the Alaska Department of Transportation was concerned about the spread of several species such as bird vetch (*Vicia cracca* L.) along highways (Nolen 2002). The USDI Bureau of Land Management and the USDI Fish and Wildlife Service are now active in collecting information about non-native plants on lands they manage (Cortés-Burns and Carlson 2006). The state's public is also contributing to our understanding of non-native species occurrences as they are becoming increasingly involved in invasive species issues in general, such as impacts of rats on seabird colonies and competition between Pacific salmon species and Atlantic salmon. Non-native plant impacts have even been addressed in recent legislation, whereby the selling of purple loosestrife (*Lythrum salicaria* L.) and orange hawkweed (*Hieracium aurantiacum* L.) would be prohibited (Alaska State House Bill 324).

After reviewing inventory data across the country it became apparent that data management and sharing of information lagged well behind actual infestations. In 2002, an Alaskan statewide invasive plant database, AKEPIC, was developed after many different land management agencies came together in 2002 (see http://akweeds/uaa.alaska.edu). We hoped that this statewide database, modeled after the Southwest exotic plant clearinghouse, would further encourage information exchange concerning invasive plant species. Indeed, the presence of a current database that incorporates information from across the state offers an opportunity to explore the patterns of non-native plant establishment and contrast it with the baseline conditions of 1941.

Based on data present in floras and the statewide database, we show that Alaska is entering a phase of both increased introductions and establishment of non-native species. While only a handful of non-native species were distributed widely in 1941 and 1968, many more have become naturalized and are spreading rapidly across the state, posing a serious threat to community integrity and ecosystem function.

METHODS

We surveyed the literature, building on a list initiated by M. Duffy and A. Batten (unpublished), to compare the number of non-native species known today to what was reported by Hultén (1941, 1968), and assigned each taxon as naturalized (or not) based on whether self-perpetuating populations were known by the authors or other experts. We also used a single taxonomic system (Integrated Taxonomic Information System, ITIS) to resolve synonymy (table 1). Taxa known from neighboring territories that have not been recorded for Alaska were removed from the list.

To estimate how changes in the number of populations have occurred over time, we compared the collection

Continued on page 125

Table 1—Non-native plant species found in Alaska

ITIS scientific name with authors	Naturalized	1941 Hulten	1968 Hulten	Extirpated	Source
Achillea ptarmica L.	-	Yes	Yes	-	1, 2, 3
Achnatherum hymenoides (Roemer & J.A. Schultes) Barkworth	-	-	-	-	3
Agropyron cristatum (Linnaeus) Gaertn.	-	-	-	-	4
Agropyron desertorum (Fisch. ex Link) J.A. Schultes	-	-	-	-	5
Agropyron fragile (Roth) P. Candargy	Nat	-	-	-	4
Agrostemma githago L.	-	Yes	Yes	Ext	1, 2, 3
Agrostis capillaris L.	Nat	Yes	Yes	-	1, 2, 3
Agrostis gigantea Roth	Nat	-	Yes	-	2, 4, 6
Agrostis stolonifera L.	-	Yes	Yes	-	1, 2, 4
Alchemilla monticola Opiz	-	-	-	-	3
Alliaria petiolata (Bieb.) Cavara & Grande	Nat	-	-	-	4
Alopecurus geniculatus L.	Nat	Yes	Yes	-	1, 2, 3, 6
Alopecurus pratensis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Alyssum alyssoides (L.) L.	-	-	-	-	7
Amaranthus albus L.	-	Yes	Yes	Ext	1, 2, 3
Amaranthus retroflexus L.	-	Yes	Yes	-	1, 2, 3, 4
Amsinckia lycopsoides Lehm.	Nat	Yes	Yes	-	1, 2, 3
Amsinckia menziesii (Lehm.) A. Nels. & J.F. Macbr.	Nat	Yes	Yes	-	1, 2, 6
Anthemis cotula L.	Nat	Yes	Yes	-	1, 2, 4
Anthemis tinctoria L.	Nat	Yes	Yes	-	1, 2
Anthoxanthum odoratum L.	Nat	Yes	Yes	-	1, 2
Anthriscus sylvestris (L.) Hoffmann	Nat	-	-	-	3
Arabis glabra (L.) Bernh.	Nat	Yes	Yes	-	1, 2, 6
Arctium lappa L.	-	-	-	-	12
Arctium minus Bernh.	-	-	-	-	13
Arrhenatherum elatius (L.) Beauv. ex J.& K. Presl	Nat	Yes	Yes	-	1, 2
Artemisia biennis Willd.	Nat	-	Yes	-	2, 10
Artemisia vulgaris L.	Nat	-	-	-	8
Asparagus officinalis L.	Nat	-	-	-	7
Asperugo procumbens L.	Nat	-	-	-	3, 10
Astragalus cicer L.	Nat	-	-	-	3, 10
Atriplex hortensis L.	-	Yes	Yes	Ext	1, 2
Atriplex patula L.	Nat	Yes	Yes	-	1, 2, 6
Avena fatua L.	-	Yes	Yes	-	1, 2, 4
Avena sativa L.	-	Yes	Yes	-	1, 2
Bellis perennis L.	Nat	Yes	Yes	-	1, 2
Berteroa incana (L.) DC.	Nat	-	-	-	3, 4, 7
Bidens cernua L.	Nat	Yes	Yes	-	1, 2

Table 1—Non-native plant species found in Alaska (continued)

ITIS scientific name with authors	Naturalized	1941 Hulten	1968 Hulten	Extirpated	Source
Bidens frondosa L.	Nat	-	Yes	-	2, 6
Borago officinalis L.	Nat	-	-	-	3
Brassica juncea (L.) Czern.	-	Yes	Yes	Ext	1, 2
Brassica napus L.	-	Yes	Yes	-	1, 2, 3, 4
Brassica rapa L.	-	Yes	Yes	-	4
Bromus hordeaceus L.	Nat	Yes	Yes	-	1, 2, 4, 6
Bromus inermis ssp. *inermis* Leyss.	Nat	Yes	Yes	-	1, 2, 4, 6
Bromus secalinus L.	Nat	Yes	Yes	-	1, 2,
Bromus tectorum L.	Nat	Yes	Yes	-	1, 2, 4
Calystegia sepium (L.) R. Br.	Nat	-	-	-	4
Camelina sativa (L.) Crantz	-	Yes	Yes	Ext	1, 2
Campanula glomerata L.	-	-	-	-	3
Campanula rapunculoides L.	Nat	-	-	-	3
Capsella bursa-pastoris (L.) Medik.	Nat	Yes	Yes	-	1, 2, 3, 4
Caragana arborescens Lam.	Nat	-	-	-	3, 4
Cardamine oligosperma Nutt.	Nat	-	-	-	6
Carthamus tinctorius L.	-	-	-	-	12
Castilleja tenuis (Heller) Chuang & Heckard	-	Yes	Yes	Ext	1, 2
Centaurea biebersteinii DC.	Nat	-	-	-	4
Centaurea montana L.	-	-	-	-	3
Cerastium fontanum ssp. vulgare (Hartman) Greuter & Burdet	Nat	Yes	Yes	-	1, 2, 3, 4
Cerastium glomeratum Thuill.	Nat	Yes	Yes	-	1, 2, 3, 4
Cerastium tomentosum L.	-	-	-	-	6
Chenopodium album L.	Nat	Yes	Yes	-	1, 2, 3, 4
Chenopodium berlandieri var. *berlandieri* Moq.	Nat	Yes	Yes	-	1, 2, 3, 4
Chenopodium rubrum L.	Nat	-	Yes	-	3, 7
Chrysanthemum segetum L.	-	-	Yes	Ext	2, 3
Cichorium intybus L.	-	-	-	-	4, 8
Cirsium arvense (L.) Scop.	Nat	Yes	Yes	-	1, 2, 3, 4
Cirsium vulgare (Savi) Ten.	Nat	Yes	Yes	-	1, 2, 3, 4
Clinopodium douglasii (Benth.) Kuntze	-	-	Yes	Ext	2, 3
Collomia linearis Nutt.	Nat	Yes	Yes	-	1, 2, 3, 4
Convallaria majalis L.	-	-	-	-	6
Conyza canadensis (L.) Cronq.	Nat	-	-	-	3, 4
Coronilla varia L.	Nat	-	-	-	14
Cotula coronopifolia L.	Nat	Yes	Yes	-	1, 2, 3
Crepis capillaris (L.) Wallr.	-	-	Yes	-	2, 3, 7
Crepis tectorum L.	Nat	-	Yes	-	2, 3, 4
Cryptantha torreyana (Gray) Greene	-	Yes	Yes	Ext	1, 2, 6
Cytisus scoparius (L.) Link	Nat	-	-	-	3, 4
Dactylis glomerata L.	Nat	Yes	Yes	-	1, 2, 3, 4
Deschampsia danthonioides (Trin.) Munro	-	Yes	Yes	Ext	6
Deschampsia elongata (Hook.) Munro	Nat	Yes	Yes	-	1, 2, 3, 4
Descurainia sophia (L.) Webb ex Prantl	Nat	-	Yes	-	4
Dianthus barbatus L.	-	-	-	-	3
Dianthus plumarius L.	-	-	-	-	4
Digitalis purpurea L.	Nat	Yes	Yes	-	1, 2, 4
Digitaria ischaemum (Schreb.) Schreb. ex Muhl.	-	-	-	-	3
Digitaria sanguinalis (L.) Scop.	-	-	-	-	5
Echium vulgare L.	-	-	-	-	3
Elodea canadensis Michx.	-	-	-	-	3
Elymus canadensis L.	-	-	-	-	5
Elymus repens (L.) Gould	Nat	Yes	Yes	-	1, 2, 3, 4
Elymus sibiricus L.	Nat	Yes	Yes	-	1, 2, 3, 4

Table 1—Non-native plant species found in Alaska (continued)

ITIS scientific name with authors	Naturalized	1941 Hulten	1968 Hulten	Extirpated	Source
Eragrostis intermedia A.S. Hitchc.	-	-	-	-	5
Erodium cicutarium (L.) L'Hér. ex Ait.	-	Yes	Yes	-	1, 2, 3, 4
Erucastrum gallicum (Willd.) O.E. Schulz	-	-	-	-	4
Eschscholzia californica Cham.	-	-	-	-	3
Euphorbia peplus L.	-	-	-	-	7
Euphrasia nemorosa (Pers.) Wallr.	Nat	-	-	-	8
Fagopyrum esculentum Moench	-	-	-	-	7
Festuca trachyphylla (Hack.) Krajina	-	-	-	-	7
Gaillardia pulchella Foug.	-	-	-	-	3
Galeopsis bifida Boenn.	Nat	Yes	Yes	-	1, 2, 3, 4
Galeopsis tetrahit L.	Nat	Yes	Yes	-	1, 2, 3, 4
Geranium bicknellii Britt.	-	-	-	-	6
Geranium carolinianum L.	-	-	-	-	7
Geranium robertianum L.	Nat	Yes	Yes	-	1, 2, 3, 7
Geranium sanguineum L.	-	-	-	-	7
Gilia achilleifolia Benth.	-	Yes	Yes	Ext	1, 2, 3
Gilia capitata Sims	-	Yes	Yes	Ext	1, 2, 3
Glechoma hederacea L.	-	Yes	Yes	Ext	1, 2, 3
Gnaphalium uliginosum L.	Nat	Yes	Yes	-	1, 2, 3, 4
Gypsophila elegans Bieb.	Nat	-	-	-	7
Gypsophila paniculata L.	Nat	-	-	-	12
Hackelia micrantha (Eastw.) J.L. Gentry	-	-	Yes	Ext	6
Helianthus annuus L.	-	Yes	Yes	-	1, 2, 3, 4
Hesperis matronalis L.	Nat	Yes	Yes	-	1, 2, 3
Hieracium aurantiacum L.	Nat	-	Yes	-	1, 2, 3, 4
Hieracium caespitosum Dumort.	Nat	-	-	-	4
Hieracium lachenalii K.C. Gmel.	Nat	-	-	-	14
Hieracium pilosella L.	Nat	-	-	-	4
Hieracium umbellatum L.	Nat	Yes	Yes	-	1, 2, 6
Holcus lanatus L.	Nat	Yes	Yes	-	1, 2, 3, 4
Hordeum comosum J. Presl	-	-	-	-	5
Hordeum jubatum L.	Nat	Yes	Yes	-	1, 2, 3, 4
Hordeum murinum L. ssp. *leporinum* (Link) Arcang.	-	-	-	-	4, 12
Hordeum vulgare L.	-	Yes	Yes	-	1, 2, 4, 8
Hypericum perforatum L.	Nat	-	-	-	4, 6
Hypochaeris radicata L.	Nat	Yes	Yes	-	1, 2, 3, 4
Iberis amara L.	-	-	-	-	3
Impatiens glandulifera Royle	Nat	-	-	-	4
Lactuca serriola L.	Nat	-	-	-	4
Lactuca tatarica (L.) C.A. Mey.	Nat	Yes	Yes	-	8
Lamium album L.	Nat	Yes	Yes	-	3
Lamium maculatum L.	-	-	-	-	7
Lappula squarrosa (Retz.) Dumort.	Nat	Yes	Yes	-	1, 2, 3, 4
Lapsana communis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Lathyrus pratensis L.	-	-	-	-	3
Leontodon autumnalis L.	Nat	-	Yes	-	2, 3, 4
Lepidium densiflorum Schrad.	Nat	Yes	Yes	-	1, 2, 6
Lepidium ramosissimum A. Nels.	Nat	-	-	-	4, 12
Lepidium virginicum L.	-	Yes	Yes	Ext	1, 2
Leucanthemum vulgare Lam.	Nat	Yes	Yes	-	1, 2, 3, 4
Levisticum officinale W.D.J. Koch	-	-	-	-	12
Linaria dalmatica (L.) P. Mill.	-	-	-	-	11
Linaria pinifolia (Poir.) Thellung	-	-	-	-	4, 12

Table 1—Non-native plant species found in Alaska (continued)

ITIS scientific name with authors	Naturalized	1941 Hulten	1968 Hulten	Extirpated	Source
Linaria vulgaris P. Mill.	Nat	Yes	Yes	-	1, 2, 3, 4
Lolium arundinaceum (Schreb.) S.J. Darbyshire	Nat	Yes	Yes	-	1, 2, 3, 4
Lolium perenne ssp. *multiflorum* (Lam.) Husnot	Nat	Yes	Yes	-	1, 2, 3, 4
Lolium perenne ssp. perenne L.	Nat	Yes	Yes	-	1, 2, 3, 4
Lolium pratense (Huds.) S.J. Darbyshire	-	-	-	-	6
Lonicera tatarica L.	-	-	-	-	8
Lotus corniculatus L.	Nat	-	-	-	4, 14
Lupinus polyphyllus Lindl.	Nat	Yes	Yes	-	1, 2, 4, 6
Lychnis chalcedonica L.	Nat	-	-	-	4
Lychnis coronaria (L.) Desr.	-	-	-	-	8
Lythrum hyssopifolium L.	-	-	-	-	7
Lythrum salicaria L.	Nat	-	-	-	4
Malva neglecta Wallr.	-	-	-	-	4
Marrubium vulgare L.	-	Yes	Yes	Ext	1, 2, 3
Matricaria discoidea DC.	Nat	Yes	Yes	-	1, 2, 3, 4
Medicago lupulina L.	Nat	Yes	Yes	-	1, 2, 3, 4
Medicago minima (L.) L.	-	-	-	-	4
Medicago polymorpha L.	-	Yes	Yes	Ext	1, 2, 3
Medicago sativa L. ssp. *falcata* (L.) Arcang.	Nat	Yes	Yes	-	1, 2, 4, 12
Medicago sativa L. ssp. *sativa*	Nat	Yes	Yes	-	1, 2, 3, 4
Melilotus alba [*officinalis* (L.) Lam.]	Nat	Yes	Yes	-	1, 2, 3, 4
Melilotus officinalis (L.) Lam.	Nat	Yes	Yes	-	1, 2, 3, 4
Mentha × *piperita* L. (pro sp.) [*aquatica* × *spicata*]	Nat	Yes	Yes	-	1, 2
Mentha spicata L.	Nat	Yes	Yes	-	1, 2, 3, 4
Microsteris gracilis (Hook.) Greene	-	Yes	Yes	Ext	1, 2, 3
Misopates orontium (L.) Raf.	Nat	-	Yes	-	1, 2, 3
Mycelis muralis (L.) Dumort.	Nat	-	-	-	4
Myosotis scorpioides L.	Nat	Yes	Yes	-	4, 6
Nemophila menziesii Hook. & Arn.	-	Yes	Yes	-	1, 2, 3
Nepeta cataria L.	-	Yes	Yes	Ext	1, 2, 3
Neslia paniculata (L.) Desv.	-	Yes	Yes	-	1, 2, 3, 4
Nymphaea odorata Ait. ssp. *odorata*	-	-	-	-	6
Onobrychis viciifolia Scop.	-	-	-	-	3
Panicum miliaceum L.	-	-	-	-	5
Papaver nudicaule L.	Nat	Yes	Yes	-	1, 2, 3, 4
Papaver rhoeas L.	-	Yes	Yes	Ext	1, 2, 3
Pascopyrum smithii (Rydb.) A. Löve	Nat	Yes	Yes	-	1, 2, 6
Pastinaca sativa L.	-	Yes	Yes	Ext	1, 2, 3
Phalaris arundinacea L.	Nat	Yes	Yes	-	1, 2, 3, 4
Phalaris canariensis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Phalaris minor Retz.	-	-	Yes	Ext	2, 3
Phleum pratense L.	Nat	Yes	Yes	-	1, 2, 3, 4
Plagiobothrys figuratus (Piper) I.M. Johnston ex M.E. Peck ssp. *figuratus*	-	Yes	Yes	Ext	1, 2, 3
Plantago lanceolata L.	-	Yes	Yes	-	1, 2, 3, 4
Plantago major L.	Nat	Yes	Yes	-	1, 2, 3, 4
Poa annua L.	Nat	Yes	Yes	-	1, 2, 3, 4
Poa compressa L.	Nat	Yes	Yes	-	1, 2, 3, 4
Poa pratensis L. ssp. *irrigata* (Lindm.) Lindb. f.	Nat	Yes	Yes	-	1, 2, 3, 4

Table 1—Non-native plant species found in Alaska (continued)

ITIS scientific name with authors	Naturalized	1941 Hulten	1968 Hulten	Extirpated	Source
Poa trivialis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Polygonum aviculare L.	Nat	-	Yes	-	2, 3, 4
Polygonum convolvulus L.	Nat	Yes	Yes	-	1, 2, 3, 4
Polygonum cuspidatum Sieb. & Zucc.	Nat	Yes	Yes	-	1, 2, 3, 4
Polygonum hydropiper L.	-	Yes	Yes	-	8
Polygonum hydropiperoides Michx.	-	Yes	Yes	Ext	1, 2, 3
Polygonum lapathifolium L.	Nat	Yes	Yes	-	1, 2, 3, 4
Polygonum persicaria L.	Nat	Yes	Yes	-	1, 2, 3
Polygonum ramosissimum Michx. var. *prolificum* Small	-	Yes	Yes	Ext	8
Polygonum sachalinense F. Schmidt ex Maxim.	Nat	-	-	-	14
Polygonum × *bohemicum* (J. Chrtek & Chrtková) Zika & Jacobson [*cuspidatum* × *sachalinense*]	Nat	-	-	-	14
Polypogon monspeliensis (L.) Desf.	Nat	-	Yes	-	2, 3
Prunus padus L.	Nat	-	-	-	3, 4
Prunus virginiana L.	Nat	-	-	-	14
Ranunculus acris L.	Nat	-	Yes	-	2, 3, 4
Ranunculus repens L.	Nat	Yes	Yes	-	1, 2, 4, 6
Raphanus sativus L.	-	Yes	Yes	-	1, 2, 3, 7
Rorippa nasturtium-aquaticum (L.) Hayek	-	Yes	Yes	-	1, 2, 7
Rosa rugosa Thunb.	Nat	-	-	-	3
Rubus discolor Weihe & Nees	-	-	-	-	4
Rubus idaeus ssp. *idaeus* L.	Nat	-	-	-	7
Rudbeckia hirta L.	-	-	-	-	3
Rumex acetosa ssp. *acetosa* L.	-	Yes	Yes	-	1, 2, 3
Rumex acetosella L.	Nat	Yes	Yes	-	1, 2, 3, 4
Rumex crispus L.	Nat	Yes	Yes	-	1, 2, 3, 4
Rumex longifolius DC.	Nat	Yes	Yes	-	1, 2, 3, 4
Rumex maritimus L.	Nat	Yes	Yes	-	1, 2, 3
Rumex obtusifolius L.	Nat	Yes	Yes	-	1, 2, 3, 4
Sagina procumbens L.	Nat	-	-	-	6
Salix × *pendulina* Wenderoth	-	-	-	-	3
Saponaria officinalis L.	-	-	-	-	4
Schedonorus pratensis (Huds.) Beauv.	Nat	-	-	-	3
Secale cereale L.	-	Yes	Yes	-	1, 2, 3
Senecio eremophilus Richards.	-	-	Yes	Ext	2, 7
Senecio jacobaea L.	Nat	-	-	-	4, 6
Senecio sylvaticus L.	-	-	-	-	4
Senecio viscosus L.	-	-	-	-	4
Senecio vulgaris L.	Nat	Yes	Yes	-	1, 2, 3, 4
Setaria viridis (L.) Beauv.	-	-	-	-	3, 4
Silene armeria L.	-	-	-	-	3
Silene dioica (L.) Clairville	Nat	-	-	-	4, 12
Silene latifolia Poir. ssp. *alba* (P. Mill.) Greuter & Burdet	-	-	-	-	3, 4
Silene noctiflora L.	Nat	Yes	Yes	-	1, 2, 3
S*ilene vulgaris* (Moench) Garcke	Nat	-	-	-	3, 7
Sinapis arvensis L.	-	Yes	Yes	Ext	1, 2, 3, 4
Sisymbrium altissimum L.	Nat	Yes	Yes	-	1, 2, 3, 4
Sisymbrium officinale (L.) Scop.	-	Yes	Yes	-	1, 2, 3
Solanum nigrum L.	-	Yes	Yes	Ext	1, 2, 3
Solanum physalifolium Rusby	-	-	-	-	7

Table 1—Non-native plant species found in Alaska (continued)

ITIS scientific name with authors	Naturalized	1941 Hulten	1968 Hulten	Extirpated	Source
Sonchus arvensis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Sonchus arvensis ssp. *uliginosus* (Bieb.) Nyman	Nat	-	-	-	3, 4
Sonchus asper (L.) Hill	Nat	Yes	Yes	-	1, 2, 3, 4
Sonchus oleraceus L.	Nat	Yes	Yes	-	1, 2, 3, 4
Sorbaria sorbifolia (L.) A. Braun	Nat	-	-	-	3, 4
Sorbus aucuparia L.	Nat	Yes	Yes	-	1, 2, 3, 4
Spergula arvensis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Spergularia rubra (L.) J.& K. Presl	Nat	Yes	Yes	-	1, 2, 3, 4
Spinacia oleracea L.	-	Yes	-	Ext	1
Stellaria media (L.) Vill.	Nat	Yes	Yes	-	1, 2, 3, 4
Symphytum asperum Lepechin	-	-	-	-	3
Symphytum officinale L.	-	-	-	-	4
Tanacetum vulgare L.	Nat	Yes	Yes	-	1, 2, 3, 4
Taraxacum laevigatum (Willd.) DC.	Nat	Yes	Yes	-	1, 2, 3, 7
Taraxacum officinale ssp. *officinale* G.H. Weber ex Wiggers	Nat	Yes	Yes	-	1, 2, 3, 4
Thlaspi arvense L.	-	Yes	Yes	-	1, 2, 3, 4
Tragopogon dubius Scop.	Nat	-	-	-	3, 4
Trifolium aureum Pollich	Nat	-	Yes	-	2, 3, 4, 7
Trifolium campestre Schreb.	-	-	Yes	Ext	2, 3, 7
Trifolium dubium Sibthorp	-	Yes	Yes	Ext	1, 2, 3
Trifolium hybridum L.	Nat	Yes	Yes	-	1, 2, 3, 4
Trifolium lupinaster L.	-	Yes	Yes	-	1, 2
Trifolium microcephalum Pursh	-	Yes	Yes	Ext	1, 2, 3, 7
Trifolium pratense L.	Nat	Yes	Yes	-	1, 2, 3, 4
Trifolium repens L.	Nat	Yes	Yes	-	1, 2, 3, 4
Trifolium variegatum Nutt.	-	Yes	Yes	Ext	1, 2, 3
Tripleurospermum perforata (Merat) M. Lainz	Nat	Yes	Yes	-	1, 2, 3, 4
Triticum aestivum L.	-	Yes	Yes	-	1, 2, 3, 4
Urtica urens L.	-	Yes	Yes	Ext	1, 2, 3
Vaccaria hispanica (P. Mill.) Rauschert	-	Yes	Yes	Ext	1, 2, 3
Veronica anagallis-aquatica L.	-	Yes	Yes	Ext	1, 2, 3
Veronica arvensis L.	-	Yes	Yes	-	1, 2, 3
Veronica chamaedrys L.	-	Yes	Yes	-	1, 2, 3
Veronica longifolia L.	Nat	-	-	-	3
Veronica persica Poir.	-	Yes	Yes	Ext	1, 2, 3
Veronica serpyllifolia ssp. *serpyllifolia* L.	Nat	Yes	Yes	-	1, 2, 3, 4
Viburnum opulus L.	-	-	-	-	4
Vicia cracca L.	Nat	Yes	Yes	-	1, 2, 3, 4
Vicia sativa ssp. nigra (L.) Ehrh.	Nat	Yes	yes	-	1, 2, 3
Vicia villosa Roth	Nat	Yes	Yes	-	1, 2, 3
Viola tricolor L.	-	-	-	-	1, 2, 3, 4
Zea mays L.	-	-	-	-	12

Sources cited are coded as follows: 1- Hultén 1941-50, 2- Hultén 1968, 3- UAF Herbarium database, 4- AK Exotic Plant Clearinghouse -Sept 2006, 5- Jeff Conn unpublished- search of Palmer Herbarium, 6- Mary Stensvold unpublished, 7- Welsh, S. Anderson's Flora of Alaska, 8- Al Batten unpublished work, 9- Bruce Bennett unpublished -Yukon weeds Oct 2004, 10- Mike Duffy unpublished work, 11- Jeff Heys personal communication, 12-Carlson, M., I. Lapina 2004, 13- Jeanne Standley personal communication, 14-Michael Shephard personal communication history of three groups of Alaskan plants: native, non-native, and non-native species considered to be invasive. The collection history of native species serves as a null expectation of overall collection intensity through time. Rather than comparing the actual number of records, we standardized the records to a proportion of total records for each group for a given year, thus allowing for comparisons among rare and common species or groups of species. For example, 36 percent (i.e., 488 collections) of the total 1,344 collections of the native plants were recorded by 1941, while 30 percent (i.e., 90) out of 305 total collections of the invasive plants were recorded by the same year.

From the updated list of non-native species, we selected 15 that are considered to be invasive or very widespread non-native species in the state, and contrasted their history of collections with their closest native relatives (phylogenetically and ecogeographically). Additionally, we compared the 15 species considered invasive with 15 randomly chosen non-native species. The number and location of collections from the earliest record to 2006 were examined. We tallied the number of herbarium samples collected within the following: Hultén (1941), Hultén (1968), and the University of Alaska, Herbarium (ALA – online database current up through 2003; see http://arctos.database.museum/SpecimenSearch.cfm). To explore how Alaska might differ from the Pacific Northwest, we compared the collection history of the chosen 15 invasive species with records in the Oregon State University Herbarium (see http://ocid.nacse.org/cgi-bin/qml/herbarium/ plants/vherb.qml). Three of these species were removed because of too few records. We conducted a second analysis combining these data with those of AKEPIC to contrast the relative proportion of all records for the species at three landmark years: 1941, 1968, and 1985 (table 2). Differences in proportion of total records in the three years were tested using a non-parametric test (Kruskal-Wallis) since the data did not meet normality assumptions. An experiment-wide Bonferroni correction was made to maintain significance at $p \leq 0.05$.

We attempted to reduce potential bias among the datasets regarding what constitutes a population record by filtering the AKEPIC inventory points through a 25 x 25 mile grid. We chose 25 mile grid cells because this is roughly the size of the ‘dots’ used by Hultén (1968), where a single dot may represent one or more individual collections. Additionally, this makes AKEPIC data comparable to ALA, which has not entered all collections into their database from a single location (A. Batten, pers. comm.).

The grid cells produce a maximum of a single collection point per grid cell. For example, although there are 209 current points of *Cirsium arvense* (L.) Scop. in the AKEPIC database, most occur within Anchorage and Haines, so when filtered through the grid there are 16 ‘sites,’ which are then comparable to ALA.

RESULTS

Reviewing the literature indicates there have been 283 non-native plant taxa recorded in Alaska to date, relative to a total flora of approximately 2,100 taxa. In 1941 Alaska had 154 non-native plant taxa, and 174 in 1968 (Hultén 1941, 1968); of the latter, 110 have since naturalized; i.e., formed self-perpetuating populations. By 2006 an additional 109 new species were added to Alaska’s flora, 47 of which have naturalized (table 1). Thus, from 1941 to 1968 roughly one non-native plant taxon was added per year, while from 1968 to 2006 nearly three taxa were annually added to the flora. We find that 36 species listed in 1941 and 1968 have not been recorded since and are presumed extirpated (table 1).

The pattern of plant collections in Alaska through time suggests that the number of herbarium collections has increased steadily for both native and non-native plants (fig. 1). There is a trend for a greater proportion of collections known by 1941 in native plants than in non-native or invasive plants. Relative to native plants, the proportion of collections for the non-native and invasive plants increases more quickly from 1985 to the present. In 1985 roughly 50 percent of the total collections had been made for invasives and non-natives, contrasting with 68 percent for the native species. Interestingly, the data of the same invasive species in Oregon show a very different relationship, with a significantly higher proportion of total collections having been made by 1968 and 1985 ($p < 0.001$, Kruskal-Wallis). This suggests that, in Oregon, collection frequency is declining over time, while in Alaska it is increasing, especially for invasive and non-native species.

Table 2—List of 15 native and non-native Alaskan plant taxa used in the analysis. The number of records is presented prior to 1941, 1941–1967, 1968–1984, 1985–2006, and the 2002–2006 AKEPIC records filtered through a 25 x 25 mile grid.

Native Species	<1941	1941–1967	1968–1984	since 1985	AKEPIC Grid	TOTAL
Cerastium arvense L.	0	15	9	19	0	43
Cirsium kamtschaticum Ledeb. ex DC.	0	3	3	6	0	12
Crepis elegans Hook.	4	30	15	10	0	59
Descurainia sophioides (Fisch. ex Hook.) O.E. Schulz	10	33	20	28	0	91
Scutellaria galericulata L.	1	32	6	10	0	49
Hieracium triste Willd. ex Spreng.	1	43	23	59	0	126
Impatiens noli-tangere L.	4	29	7	7	0	47
Penstemon gormanii Greene	1	20	11	12	0	44
Lupinus arcticus S. Wats.	6	95	48	42	0	191
Phleum alpinum L.	0	170	10	45	0	225
Polygonum caurianum B.L. Robins.	2	28	5	5	0	40
Ranunculus occidentalis Nutt.	5	31	32	67	0	135
Tephroseris palustris (L.) Fourr.	7	95	33	31	0	166
Taraxacum phymatocarpum J. Vahl	0	13	10	68	0	91
Lathyrus palustris L.	1	60	26	21	0	108
Invasive or widely distributed species						
Cerastium fontanum Baumg.	8	4	7	21	30	70
Cirsium arvense (L.) Scop.	2	2	1	5	16	26
Crepis tectorum L.	0	1	4	14	59	78
Descurainia sophia (L.) Webb ex Prantl	5	0	0	3	8	16
Galeopsis bifida Boenn. (combined with G. tetrahit)	5	0	0	0	31	36
Hieracium aurantiacum L.	0	5	4	1	19	29
Impatiens glandulifera Royle	0	0	0	0	3	3
Linaria vulgaris P. Mill.	1	2	7	10	54	74
Melilotus alba Medik.	2	2	2	4	55	65
Phleum pratense L.	25	1	3	12	65	106
Polygonum aviculare L.	8	17	10	22	55	112
Ranunculus acris L.	4	3	2	10	4	23
Senecio jacobaea L.	0	0	0	0	6	6
Taraxacum officinale ssp. *officinale*	29	0	4	18	139	190
Vicia cracca L.	1	4	5	5	27	42
Randomly selected non-native species						
Agrostis stolonifera L.	12	2	4	1	6	25
Caragana arborescens Lam.	0	0	1	3	3	7
Conyza canadensis (L.) Cronq.	0	0	1	3	2	6
Erodium cicutarium (L.) L'Hér.Ait.	1	0	1	3	1	6
Geranium robertianum L.	1	0	1	0	0	2
Hesperis matronalis L.	1	0	1	1	0	3
Lamium album L.	1	0	1	0	1	3
Leontodon autumnalis L.	0	0	0	1	10	11
Lolium perenne L. ssp. *multiflorum*	1	0	0	4	18	23
Nemophila menziesii Hook. & Arn.	2	0	0	1	0	3
Neslia paniculata (L.) Desv.	3	0	0	0	1	4
Polygonum cuspidatum Sieb. & Zucc.	0	0	2	2	16	20
Rumex longifolius DC.	0	0	6	1	5	12
Secale cereale L.	1	1	0	0	0	2
Silene vulgaris (Moench) Garcke	0	0	1	0	1	2

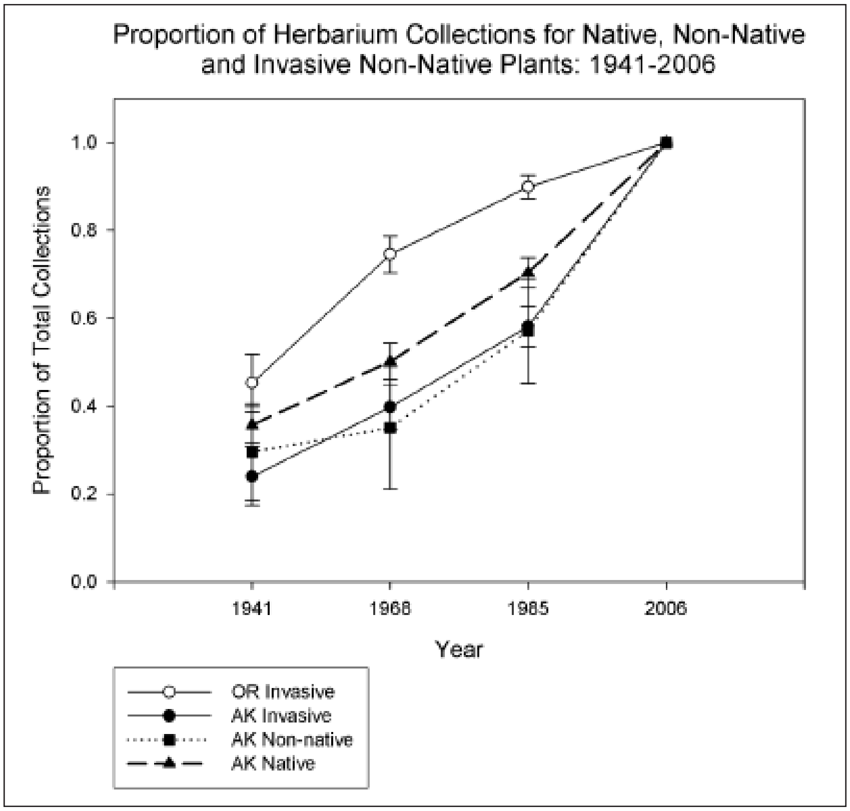

Figure 1—Mean proportion of collections over time relative to the cumulative total in 2006 for 15 invasive, non-native, and native plants in Alaska. Proportion of collections in Oregon is displayed for 12 of 15 of the invasive species. The means of the 15 species in each group are displayed as symbols and standard errors are also included.

If records from the AKEPIC database are added to the herbarium records, a recent and exponential growth pattern is observed for both non-native and invasive species (fig. 2). The two groups began with roughly the same proportion of records in 1941. While the non-natives increased more steadily, displaying a significantly greater proportion by 1985 ($p = 0.024$, Mann-Whitney), the invasive group rose dramatically after 1985, with 81 percent of all species collections having been made in the last 20 years.

The overall number of records is on average an order of magnitude greater for native species than for non-native and invasive species. When AKEPIC data are included, the number of records of invasive and non-native species is still less than half that of native species for any given year (table 2).

The pattern of records over time differed for individual species among the three Alaskan species groups (native, non-native, and non-native and invasive). Individual native species differed substantially among one another in 1941, with more than half of the total collections recorded by this time for four of the 15 species (fig. 3). Four native species, including *Taraxacum alaskum* Rydb., the rare *Cirsium kamtschaticum* Ledeb. ex DC., and geographically restricted *Penstemon gormani* Greene had very few of the total collections known until after 1985. Individual invasive species all showed a consistent pattern of exponential growth (fig. 4), while the non-native species differed dramatically from one another in the proportion of records over time (fig. 5). No more than 35 percent of the total collections had been made for any of the species in the invasive group by 1941, and in two cases no records were known until after 1985. By comparison, five of 15 non-native species had more than 50 percent of the records made by 1941, while seven species were not known until after 1968.

DISCUSSION

The flora of Alaska, like all other states, is clearly in flux due to introductions of non-native species. A relatively

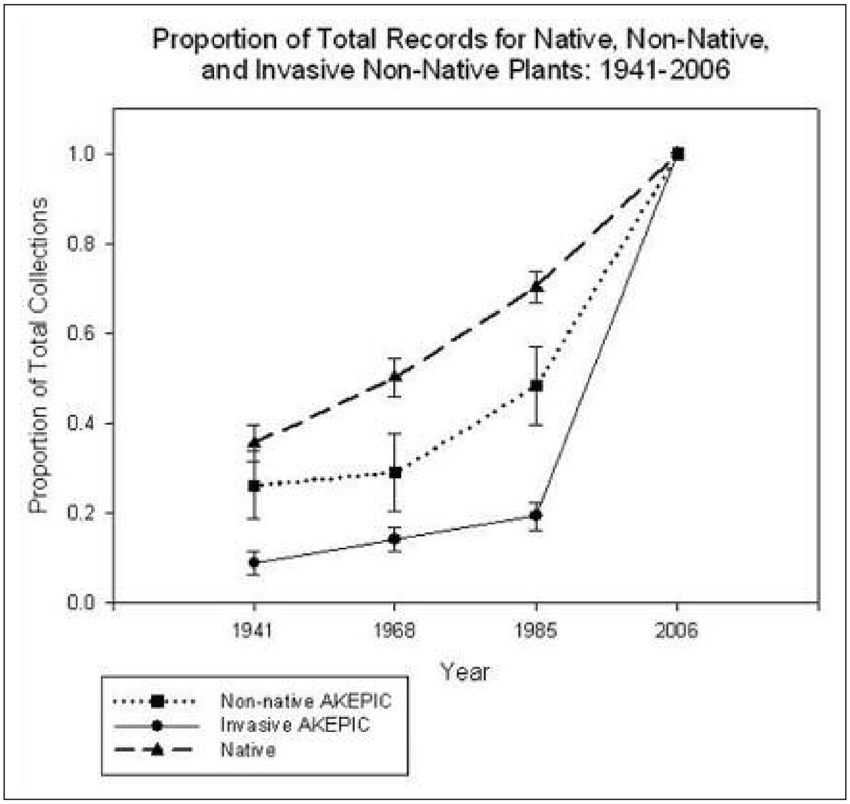

Figure 2—Mean proportion (and standard error) of all records, including the AKEPIC database, over time of 15 invasive, non-native, and native plants in Alaska.

severe climate and low levels of anthropogenic landscape changes have not offered an effective barrier to non-native plants, and a more proactive approach is necessary if the state wishes to maintain its natural ecosystems. While the proportion of non-native to native species is still relatively small (14 percent vs. *ca.* 30 percent for Oregon; T. Kaye pers. comm.), a growing number of non-native plants is being collected every year. Further, there is an increase in observations of species moving off of the anthropogenic footprint and into more intact ecosystems, often in habitats with natural disturbance (Carlson and Lapina 2004).

The increase in non-native plants mirrors a similar increase in human population for the state, which has tripled since 1968 (U.S. Census 2000). With it, the amount of ground disturbing activities related to oil development, agriculture, housing, and roads has also dramatically increased. When human disturbance was low, such as the decade after Alaska became a state, the probability that a non-native plant species would find its way to Alaska and become established was small. In this context, it is interesting to note that the majority of non-native plants recorded in Alaska by the mid 20th century were restricted to southeastern Alaska, which was the population center, and is also the region that has seen the greatest proportion of species actually establish. Currently, we are witnessing a geographic shift in the center of introductions, with an increasing number of non-native species establishing in south central and central Alaska, where the human population and development is now greatest.

Overall, our study indicates that the number of non-native plant population records (including those considered invasive) follows an exponential growth pattern, in contrast to that of native species, which is linear. The greater increase in non-native plant records is likely due to both an escalation in establishment and a stepped-up survey effort, two factors that are difficult to disentangle with these data alone. However, comparisons of only herbarium records indicate that the number of collections of non-native and

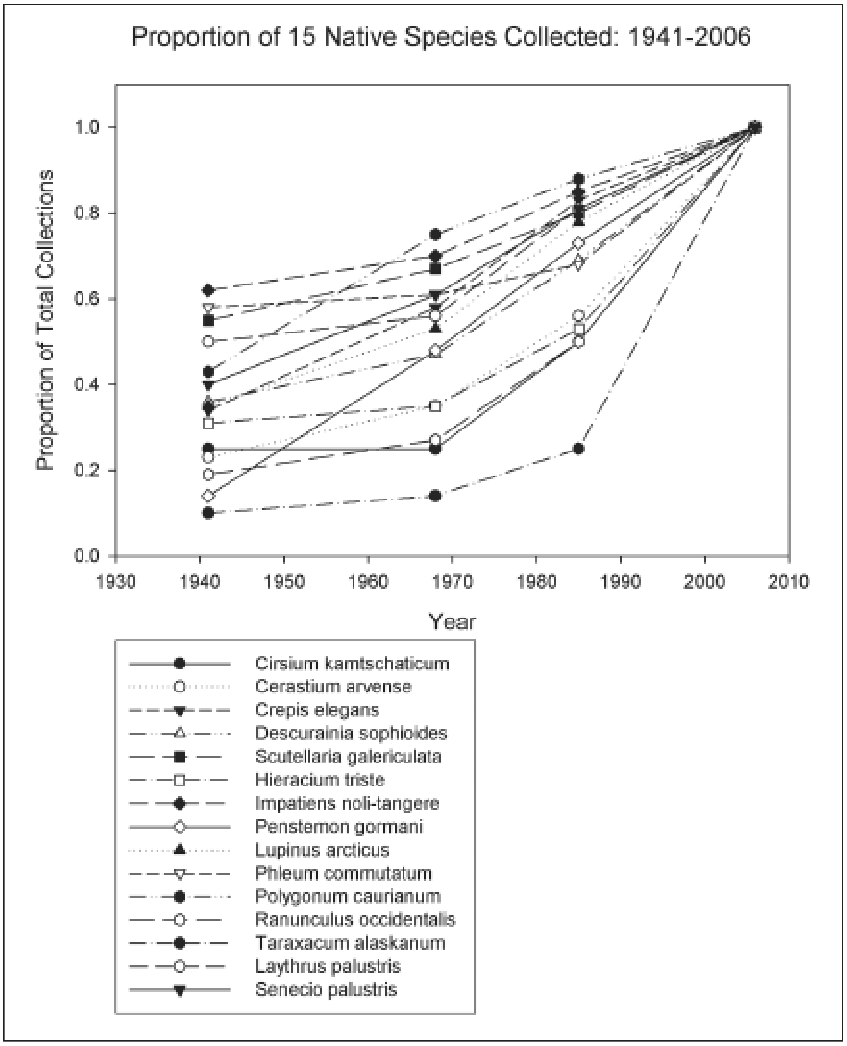

Figure 3—Proportion of all records over time of 15 native plants in Alaska.

invasive taxa is increasing more quickly than those of natives. Additionally, when comparing species considered invasive relative to a random sample of non-native species in the combined data set, we see that the invasives are showing a greater increase in number of populations recorded in recent years. Given these trends, we propose that this increase is not just due to increased survey effort.

Species invasions can be characterized as going through the phases of 1) establishment (when population growth is often highly irregular), 2) rapid population growth and expansion, and 3) reduced growth and slowed spread (Kinlan and Hastings 2005). In Oregon, invasive species appear to be in the reduced growth phase. The same species in Alaska, however, are all behaving as populations in the establishment and rapid population growth phases. Taken together, these trends suggest that Alaska is not necessarily less susceptible to invasion, but that the process of invasion has been delayed by a number of decades. We further propose what we are now seeing in Alaska is the establishment of individual foci in various locations of where human disturbance and the propagule pressure are large enough to promote establishment. For example, in Valdez, there is now a large infestation of *Hieracium caespitosum* Dumort. that must have been established some time in the last decade. Otherwise, this species is only known from a few disparate and small populations (M. Shephard pers. obs.).

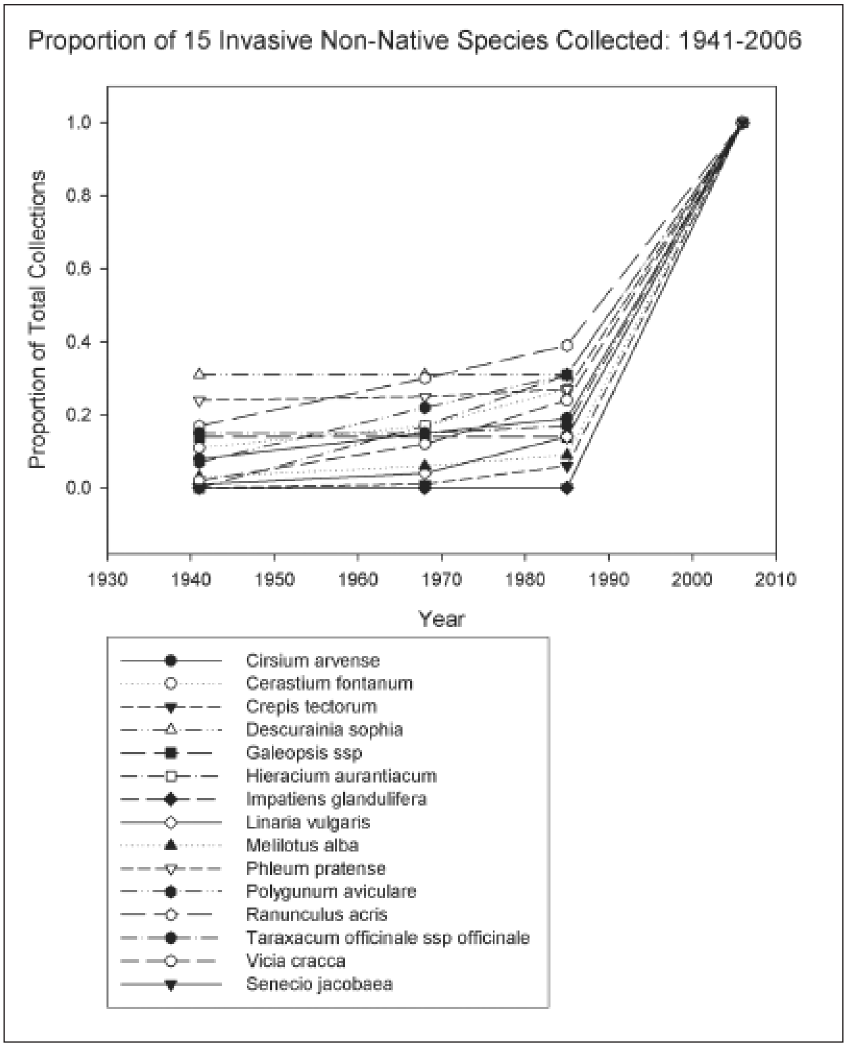

Figure 4—Proportion of all records over time of 15 invasive plants in Alaska.

In many instances, the spatial and temporal patterns of expansion and establishment of non-natives across Alaska mirror those known from the rest of the continent. *Crepis tectorum* L., *Hieracium aurantiacum* L., and *Hypochaeris radicata* L. all are expanding rapidly in the western United States and they appear to be in an exponential growth phase within Alaska. In 1968 there were only one or two collections of these plants in Alaska, whereas now AKEPIC and additional unpublished data suggest these taxa are all spreading rapidly. The Kodiak Wildlife Refuge and the Koniag Native Corporation have been jointly trying to control a large infestation of *H. aurantiacum* within native plant communities across a remote 40 acre island.

Hypochaeris radicata was one of the most common roadside weeds, often exceeding 30 percent cover, on Prince of Wales Island in southeastern Alaska (unpublished report, for the USDA Forest Service). *Crepis tectorum* is now extremely abundant along roads throughout Alaska, and is beginning to show up on glacial river floodplains.

Other taxa, such as *Phalaris arundinacea* L., *Trifolium repens* L., *T. hybridum* L., and *Melilotus alba* Medikus were previously used for roadside seeding. Today these species visually dominate many road systems across the state, and are known to be spreading into wetlands and riparian areas.

There are still other species such as *Impatiens glandulifera* Royle, *Senecio jacobaea* L., and *Centaurea*

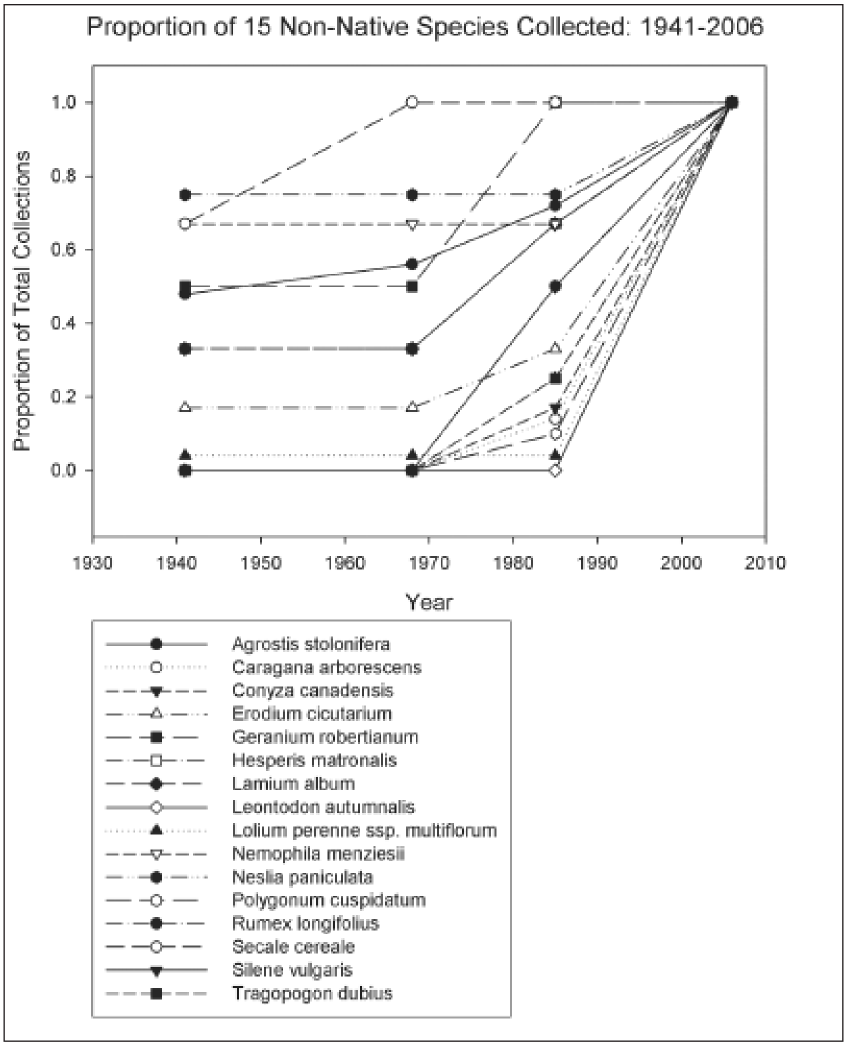

Figure 5—Proportion of all records over time of 15 non-native and invasive plants in Alaska.

bierbersteinii D.C. that were completely unknown to be naturalized in the state before 1985. *Impatiens glandulifera* was probably planted in gardens, then escaped and is now well entrenched in a beach meadow in southern Alaska. *Senecio jacobaea* likely arrived via road and logging equipment, and is now very widespread in Ketchikan and occurs in small, scattered populations further north. Likewise, *C. bierbersteinii* has probably hitchhiked to Alaska on equipment, and is currently known from at least ten different locations along roads, from Anchorage to Ketchikan (all populations ranged from 1- 50 plants).

Some taxa such as *Descurainia sophia* (L.) Webb ex Prantl, *Ranunculus acris* L., and *Lonicera tatarica* L. are considered problematic invasive species outside of Alaska. In Alaska *D. sophia*, and *R. acris* are naturalized but populations tend to be small and isolated and are not particularly problematic. *Lonicera tatarica*, which is widely planted in southern and central Alaska, never has naturalized to our knowledge. Perhaps these taxa are in a 'lag phase' or will never become established in Alaska.

Alaska does have some invaders that have not been particularly problematic in the contiguous U.S. states. For example, Siberian rye (*Elymus sibiricus* L.) was introduced at the University of Alaska experimental station in Palmer and is now showing up on sandy soils in south-central Alaska and even relatively remote river bars. Siberian peashrub (*Caragana arborescens*) has been planted as an ornamental shrub and hedge in interior and southern Alaska for many decades and it is now readily recruiting in undisturbed boreal forests in Alaska. It has also recently been found to be quite invasive in Elk Island National Park in Alberta, Canada (Henderson and Chapman 2006).

A number of introductions also appear to have failed, as expected. Species such as *Spinacia oleracea*, *Nepata cataria*, and *Plagiobothrys figuratus* were known only from a few collections 65 years ago and no additional records have been noted since. The majority of the failed introductions are agricultural species or agricultural weeds, which often are not effective competitors outside of cultivation. Nonetheless, it should be noted that even apparently poorly adapted agricultural species have responded quickly to natural selection and are now invading native habitats (e.g. *Melilotus officinalis* and *M. alba*, cf. Klebesadel 1992).

Undoubtedly, many of the current and future introductions in Alaska will go extinct locally, but others will result in establishment and potentially affect habitats and ecosystem functioning. Efforts to identify which of those species will cause greatest ecological harm are currently being undertaken (Carlson et al. manuscript in prep.).

Many land management agencies, as well as the public, are becoming mobilized to reduce potentially negative impacts due to non-native plants. Primarily, the response has been to identify which species are here, where they are located, and how fast they are spreading. This information is critical in designing effective and efficient control measures. Additionally, we need to develop a better understanding of the pathways of dispersal and establishment, and of how ground disturbing activities contribute to invasion.

CONCLUSION

Alaska occupies a unique and advantageous position relative to the rest of the states: the majority of land has not been impacted by human development, and non-native plants are still largely concentrated in high-use areas. However, invasive non-native plants are quickly colonizing undeveloped areas (cf. Conn et al. in press). Once they become established in undeveloped areas, eradication and control efforts will be extremely expensive and logistically challenging, if not impossible. Consequently, the only effective way of maintaining the uniquely native flora of Alaska is by reducing the influx of non-native species into developed areas and by controlling the invasive species before they reach natural systems.

ACKNOWLEDGMENTS

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CHALLENGES IN PREDICTING THE POTENTIAL DISTRIBUTION OF INVASIVE SPECIES USING HABITAT DISTRIBUTION MODELS

Chad C. Jones[1], Steven A. Acker[2], and Charles B. Halpern[3]

ABSTRACT

Habitat distribution models (HDMs) are increasingly used in conservation biology and have the potential to inform efforts to monitor invasive species. However, several challenges complicate the use of HDMs for invasive species. First, these models assume that the species are in equilibrium with the environment, which is generally not the case with invasive species. Second, data on current distributions of invasive species usually come from a variety of sources, often leading to a clumped distribution of sample points. Third, many modeling techniques are sensitive to the recorded frequency of the species. Fourth, modeling techniques vary in their assumptions and data requirements and it is unclear which techniques work best for invasive species. We illustrate these challenges by modeling the potential distribution of three invasive species on the Olympic Peninsula, Washington. We tested three modeling techniques and assessed their sensitivities to these challenges. We found that models were sensitive to the level of clumping in the current species and are affected by the fact that species are still spreading. We provide suggestions for improving modeling efforts in the future.

KEYWORDS: Habitat distribution models, HDM, monitoring.

INTRODUCTION

Monitoring for invasive species is both time consuming and costly. Therefore, if land managers can target monitoring efforts to areas where the invasive species are likely to occur, they can maximize the effectiveness of limited resources. Habitat distribution models (HDMs) are currently widespread in conservation biology ecology (Guisan and Zimmermann 2000) and are beginning to be used to predict the potential distributions of invasive species.

However, several challenges complicate the use of HDMs for invasive species. First, these models assume that species are in equilibrium with their environments (Guisan and Zimmermann 2000), but this is generally not the case with invasive species, which are still spreading. Dynamic species distributions may bias model results by creating spurious correlations with habitat variables. Most importantly, we cannot test how well the models predict the potential distributions of spreading species, only how well they predict current distributions. Furthermore, data on current distributions of invasive species usually come from a variety of sources and are usually not from a coherent or balanced sampling design (although this is changing). This can lead to clumped distributions of sample points and may affect how common a species is in the dataset. Some modeling techniques only require information on species presence but most require information on both presence and absence. Those that require both presence and absence information are sensitive to how frequent the invasive species is in the dataset (i.e., the percentage of plots where the species is present). Therefore, if the distribution of the sample points affects frequency, it can greatly affect results.

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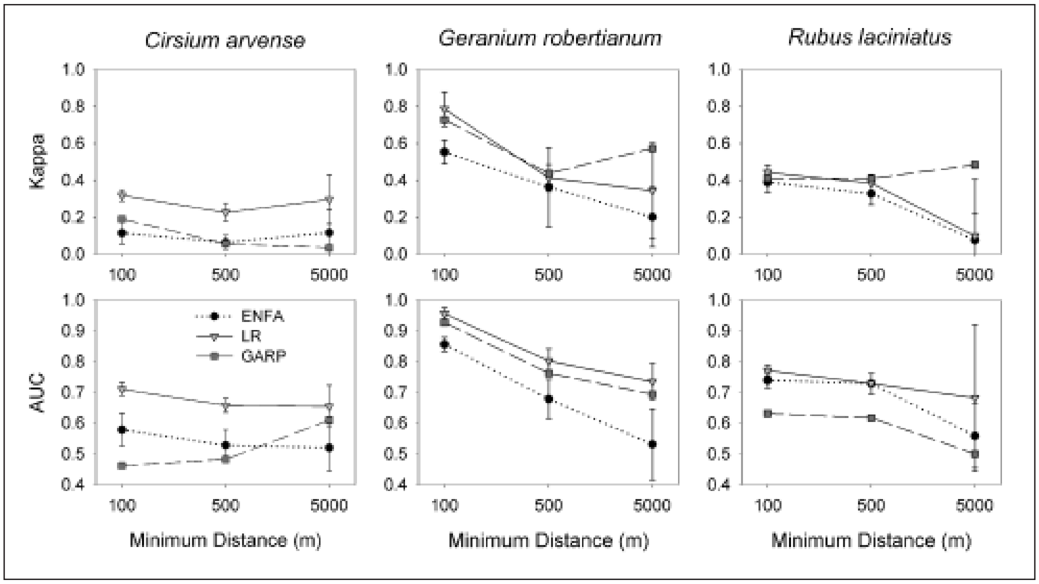

Figure 1—Model accuracy with different minimum distances for three species and three modeling techniques. Values of Kappa >0.6 are good; 0.2-0.6 are moderate, and <0.2 are poor (Landis and Koch 1977). Values of AUC >0.9 are good, 0.7-0.9 are moderate, and <0.7 are poor (Pearce and Ferrier 2000).

We illustrated these challenges by modeling the potential distributions of three invasive species on the Olympic Peninsula, Washington: Canada thistle (*Cirsium arvense* (L.) Scop.), herb robert (*Geranium robertianum* L.) and evergreen blackberry (*Rubus laciniatus* Willd.). We used three different modeling techniques and assessed their sensitivity to these factors. We asked four questions: 1) How does clumping of sample distributions affect model results? 2) How might spreading species affect model results? 3) How does frequency affect the predictions of presence/absence methods? 4) How do the results of the different modeling techniques compare? We use specific examples to illustrate the answers to these questions.

METHODS AND RESULTS

HDMs require data on the species locations (presence or absence) and maps of habitat variables thought to affect the potential species distributions. We combined 13 datasets from a variety of sources with a total of 4142 data points across the Olympic Peninsula. For each model we divided the data into five equal parts and used four-fifths to build the model and one-fifth to test it. We repeated this with the five partitions of the data to yield five replicate models. We developed models using one presence/absence technique, logistic regression (Nicholls 1989), and two presence-only techniques, Ecological Niche Factor Analysis (ENFA, Hirzel et al. 2002) and Genetic Algorithm for Rule-set Prediction (GARP, Stockwell and Peters 1999). Models for GARP have not yet been completed and at this point include only one replicate. Because of the low frequency of the species in the dataset, we artificially set the frequency to 50 percent by keeping all presence records and randomly removing absence points until there were equal numbers of presence and absence points. We used 12 habitat variables in the models including measures of climate (e.g., annual precipitation, number of frost days), topography (e.g., slope, heat load) and vegetation (e.g., conifer and total vegetation cover).

To test the effect of clumped distribution on modeling results we set a minimum distance between plots and randomly removed plots that were closer than this distance. Increasing the minimum distance between plots decreased clumping in the dataset but also reduced sample size. We ran models at minimum distances of 100, 500, and 5000 m. Sample size decreased from 219-559 presences at 100 m to 35-67 presences at 5000 m. We found that model accuracy,

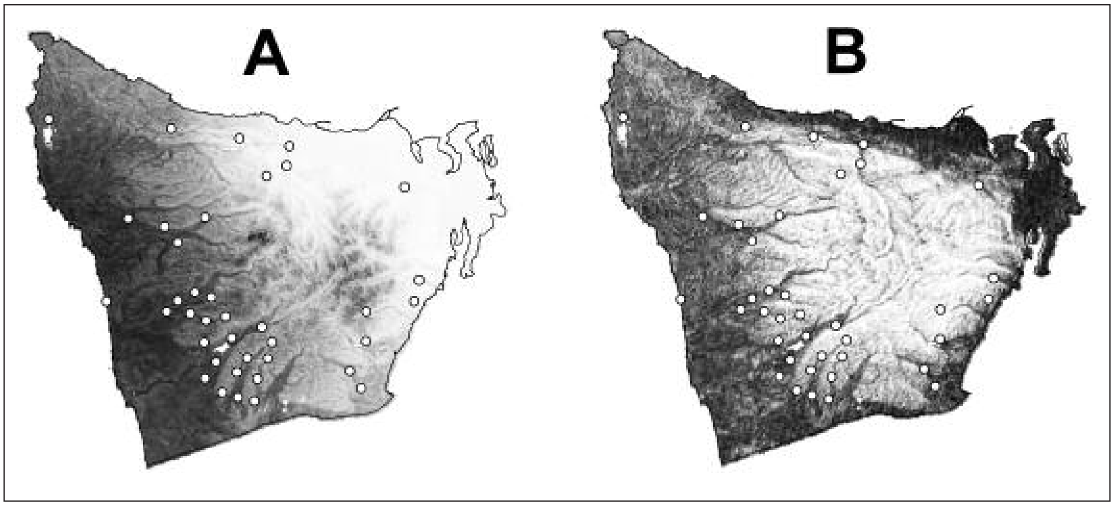

Figure 2—Habitat suitability maps for *Rubus laciniatus* based on logistic regression with a minimum distance of 100 m (A) and 5000 m (B). Darker shading indicates greater habitat suitability and open circles indicate points where the species is present at the given minimum distance between plots.

as measured by Kappa and AUC (see Fielding and Bell 1997), generally decreased with increasing minimum distance (fig. 1), likely a result of smaller sample size. However, habitat suitability maps suggest a different result. For example, logistic regression models for *Rubus laciniatus* predict that the most suitable habitat occurs on the west side of the peninsula when the minimum distance is set at 100 m (fig. 2a). This is because most occurrences of *Rubus* are in the west. However, *Rubus* can and does occur on the eastern side of the peninsula. When the minimum distance is increased to 5000 m, the model more accurately reflects the full distribution of the species (fig. 2b).

The effect associated with spread of species is illustrated by model results for *Geranium robertianum*, which first arrived on the northeastern part of the peninsula near Port Angeles. In the past 5-10 years it has spread to the western side of the peninsula, but is still much more common in the northeast. This dispersal gradient is closely matched by a gradient in precipitation frequency, which appears as an important habitat variable in the models. However, this relationship may be spurious. It is likely that the current distribution of *Geranium robertianum* reflects patterns of introduction and spread rather than precipitation.

We tested the effects of frequency on logistic regression models by artificially varying the numbers of absence data points to create frequencies of 50, 33 and 20 percent for each species. As frequency increased, model accuracy increased and habitat suitability increased. At a frequency of 20 percent only a small area in the immediate vicinity of current locations was considered suitable.

Some recent studies have suggested that presence-only techniques would perform better than logistic regression for spreading species (e.g., Hirzel et al. 2001). However, we found that logistic regression was generally more accurate in predicting the current distribution of the species (fig. 1).

CONCLUSION

In conclusion, HDMs can be used to model the distributions of invasive species, but must be used with care. Clumped sample distributions and the fact that species are still spreading can greatly affect modeling results. Logistic regression performed somewhat better than ENFA and GARP, but is very sensitive to frequency. However, measures of accuracy, such as Kappa and AUC, can only be used to assess predictions of current species distributions. For invasive species, we are more interested in predicting potential distributions, which cannot be tested directly. To better achieve this goal and overcome the challenges of using HDMs for invasive species, we recommend the following: first, when using logistic regression, absences should be removed to obtain a high frequency (e.g., 50 percent). Second, sampling designs should capture the entire current distributions of the species rather than focusing on areas with the greatest invasion. Third, decisions about model performance should not be based entirely on mea-sures of accuracy. Examining the distribution maps produced by models can provide insights into which models are best. Additionally, combining model results with information on the biology of species from their native ranges or other invaded areas can allow better model assessment. These approaches will enable the use of HDMs to more accurately inform invasive species monitoring.

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THE INTEGRATED NOXIOUS WEED INVASIVE SPECIES PROJECT (INWISP) OF WASHINGTON STATE

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ABSTRACT

Washington State is facing an invasion of non-native, highly competitive noxious weeds. For example, in the mid-1980's, approximately 60,000 acres of Ferry County were mapped by Washington State University (WSU) as noxious weed infested, with more than 400,000 acres of rangeland threatened in the county. The survey also mapped 420,000 acres infested in Washington State with diffuse knapweed (*Centaurea diffusa*) with spread calculations of over 12 million acres by 2007! These non-native noxious weeds reduce biological diversity, decrease forage, increase erosion potential, and decrease land values across the state and throughout the western U.S. The health of these grasslands is vital for wildlife, livestock, and people of Washington. Washington State land managers and owners often do not have the time, funds, or expertise to implement fully integrated weed control as part of their weed management strategies. The Integrated Noxious Weed Invasive Species Project (INWISP) addresses this technical transfer need by enhancing education and engaging land managers for better understanding of weed control. It focuses on enhancing early detection, rapid response, and integrated control to help address weed problems.

KEYWORDS: Integrated weed control, biological control, early detection-rapid response, INWISP.

PROJECT DESCRIPTION

Since 1999, Dan Fagerlie, INWISP Director, has worked with the USDA Forest Service, WSU, USDA APHIS, Washington Department of Fish and Wildlife, Colville Tribes, and the Extension and Weed-Board Offices of several counties, to assemble a team to work on these efforts. Initially, the growing team worked to expand the use of biocontrol agents in northeastern Washington to fight invasive weeds. With additional Forest Service funding, the program expanded across Central Washington in 2002 and part of western Washington in 2003, and expanding to serve throughout western Washington in 2006. The statewide project added enhanced weed control education in 2004, and an early detection and rapid response component in 2006. The Confederated Tribes of the Colville Reservation have been major partners from the beginning of the project, with the Yakama Tribe participating in recent years.

Significant reductions of targeted invasive species are occurring as a result of this collaborative project. We are observing not only a great reduction in the rate of spread, but landscape changes with diffuse knapweed, *Centaurea diffusa* Lam., monocultures returning to grasses and forbs across eastern Washington. There has also been a dramatic reduction in the rate of spread of Dalmatian toadflax,

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Linaria dalmatica (L.) P. Mill., across the state of Washington and the western United States. The project collection areas are the major source for insects that are having a remarkable impact on the toadflax in these areas. Areas of initial releases are already showing dramatic reductions in density of this invasive weed and the insects are seeking out scattered, isolated infestations. The project also provides the base funding, matched by collaborators, for the western Washington Coordinator.

CHALLENGES OF INVASIVE PLANT CONTROL IN WESTERN WASHINGTON

Invasive plant control in western Washington presents some interesting challenges to land managers. First, environmental conditions can vary widely between regions. For instance, dramatically different precipitation levels can produce a range of conditions from desert-like grassland (e.g., Sequim) to temperate rainforest (e.g., Forks). The result of such differences in water availability can alter plant size and possibly growth patterns, particularly in high precipitation areas. Environmental conditions can also impact the biological control agents used to manage weed species. Most biocontrol agents are native to environments similar to eastern Washington habitats. Using these same agents in western Washington conditions and predicting similar results as other areas in North America may not be realistic and requires further exploration.

Second, invasive species can have different and often stronger impacts on island plant communites compared to mainland communities. Special considerations are required with all aspects of invasive species management in such landscapes to minimize these impacts.

Third, diverse land use practices, including farm (large-scale to "hobby farms"), range, timber and intensely urban areas are widespread in western Washington. Challenges lie in effectively controlling invasive species while considering many landowners each with different land-use goals, weed problems and control strategies.

Fourth, although land managers have been implementing biological control as part of their integrated weed management programs, they rarely have the time, funds or expertise to use this tool to its full potential. WSU Extension's INWISP is assisting land managers in meeting these challenges by providing information, education, resources and the first organized biocontrol effort in western Washington.

PROJECTS CRITICAL TO WESTERN WASHINGTON

Two projects that are particularly important in western Washington are the control of purple loosestrife (*Lythrum salicaria* L.) in tidal-influenced water and the potential new biocontrol agent for Scotch broom (*Cytisus scoparius* (L.) Link). *Galerucella calmariensis* L. and *G. pusilla* (Duft.) (Coleoptera: Chrysomelidae), (purple-loosestrife foliage feeding beetles) have been greatly successful in many areas of the U.S., including much of Washington. However, the beetles rarely tolerate the regular inundation of water at purple loosestrife infestations that occur in areas influenced by tides. Examples of such areas include the Columbia River, rivers in Pacific and Grays Harbor Counties and the Snohomish Estuary. Two other biocontrol agents are available and appear to be tolerant of tidal-influenced environments: the flower-bud feeding weevil, *Nanophyes marmoratus* Goeze (Coleoptera: Brentidae), and the root-feeding weevil, *Hylobius transversovittatus* Goeze (Coleoptera: Curculionidae). *Nanophyes marmoratus* is available for limited redistribution. *Hylobius transversovittatus*, however, is difficult to collect and large numbers are rarely obtained. In 2007, rearing of *H. transversovittatus* will begin in Washington in order to build large numbers of weevils for redistribution.

Scotch broom is a dominant invasive species in much of western Washington. In 2005, the accidentally introduced mite, *Aceria genistae* Nalepa (Acarina: Eriophyidae) (confirmation still required) was discovered in the Tacoma/Seattle area. The mite appears to reduce seed production and biomass and when abundant may cause stem-dieback. WSU, King County Extension, USFS, Rocky Mountain Research Station and Oregon Department of Agriculture are collaborating to determine if the mite is host-specific to Scotch broom. Greenhouse and open-field tests were conducted in 2006 to test if the mite would attack native plants (e.g., species in the genera *Lupinus*, *Thermopsis*, and

Lathyrs) and crop species (e.g., soybeans). Tests will likely continue in 2007. If Scotch broom is the only species attacked by the mite a request will be submitted to USDA APHIS for its approval as a biocontrol agent. Once approved, the mite will be available to distribute throughout Washington, Oregon and California.

CONCLUSION

INWISP's implementation of integrated weed management tools assists in the effort to impact invasive plant species throughout Washington. Collaborations and funding through federal, state and local entities have been critical in allowing the successes we have had to date. These successes are evidenced through changes in landscapes towards more desirable conditions and reductions in the rate of landscape degradation from new invaders.

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DISTRIBUTION AND ABUNDANCE OF INVASIVE PLANTS IN PACIFIC NORTHWEST FORESTS

Andrew Gray[1]

ABSTRACT

The ongoing arrival and invasion of Pacific Northwest ecosystems by non-native plant species is well-known amongst most botanists and land managers in the region. However, there are few comprehensive sources of information to describe the extent and impact of these invasions to policy-makers and the public. The objective of this study was to assess the ability of different types of information systematically collected across the region to describe the distribution and abundance of invasive species in the forests of the Pacific Northwest. Cover of the most abundant species was measured on 4,169 "standard" Forest Inventory and Analysis (FIA) sample points across Oregon and Washington from 2001–2005. Intensive measurements of all vascular plant species were collected on a systematic "intensive" subset of the standard plots, with 201 assessed to date. Plant cover was estimated on four 0.017 ha subplots at each plot location. Sixty-three percent of all intensive sample points had at least one non-native species recorded; proportions ranged from 100 percent in the dry Columbia Plateau and Basin and Range eco-regions to 33 percent in the North Cascades eco-region. The majority of the non-native species found were composites or graminoids, tended to be shade-intolerant, and were found in dry or recently-disturbed forest types. The most frequent invasive species found were *Bromus tectorum* L., *Hypericum perforatum* L., and *Rubus laciniatus* Willd., but several non-native species that are not considered invasive were equally common, including *Mycelis muralis* (L.) Dumort., *Tragopogon dubius* Scop., and *Digitalis purpurea* L. Although not common, some shade-tolerant species are locally important, particularly *Ilex aquifolium* L. in lowland west-side forests. The average cover of non-native plants on plots in Oregon and Washington was 5.4 percent, suggesting that non-native plants cover 1,153,000 ha of forest land in the two states. Results indicate that non-native plants are already an important component of forests in the Pacific Northwest, even though many of the recently-arrived invasive species of concern have yet to make a substantial impact.

KEYWORDS: Forest Inventory and Analysis program, Oregon, Washington, non-native plants, forest.

INTRODUCTION

The invasion of non-native plants into new areas has had a large impact on natural and managed ecosystems. Invasive plants can directly affect the composition and function of ecosystems. They may also have a large economic impact, by changing or degrading land use, or through the costs of eradication efforts. These impacts are estimated to cost the U.S. economy at least $35 billion per year (Pimentel et al. 2005). Non-native plant invasions affect ecosystems and land use by competitively excluding desired species and altering disturbance regimes, and they are a primary cause of extinction of native species (D'Antonio and Vitousek 1992, Vitousek et al. 1996, Mooney and Hobbs 2000).

As a result of their impact on managed and natural ecosystems, the prevalence of non-native invasive plant species is a key element of many efforts that assess

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ecosystem health and sustainable management (Anonymous 1995, National Research Council 2000, Heinz Center 2002). Nevertheless, there is little data on the abundance, distribution, and impact of invasive plants available (Blossey 1999). Information is often incomplete or available for only a few species in a few areas for selected time periods. As a result, it is cur-rently not possible to provide a comprehensive understanding of the abundance and impacts of non-native invasive plants in the United States (National Research Council 2000, Heinz Center 2002).

The objective of this study was to assess the ability of different types of information systematically collected across the region to provide insights on the distribution and abundance of invasive species in the forests of the Pacific Northwest.

METHODS

The Forest Inventory and Analysis program (FIA) is a nationwide program of the USDA Forest Service with a mandate to report on the status and trends of the nation's forest resources. Classified remotely-sensed images (historically aerial photo points, currently satellite images) are used to post-stratify field plot data and improve the accuracy of inventory estimates. A systematic grid of field locations has been established on a 4.9 km spacing (one point per 2,400 ha), hereafter referred to as the "standard" plots. Ground data are collected on any field location with "forest land," defined as land areas ≥0.4 ha in size that support, or have supported, ten percent canopy cover of trees and are not primarily managed for a non-forest land use. Additional measurements are taken on one out of every 16 standard locations (one point per 38,800 ha), hereafter referred to as "intensive" plots. The plot grids extend across all land types and all ownerships, and a nationally standardized sampling approach has been in place since 2001. Earlier inventory designs, which did not sample all ownerships and/or used different plot designs in different areas, are not discussed here, although data have been useful for assessing some invasive species (Gray 2005).

This study describes measurements of non-native plants on 4,169 "standard" and 201 "intensive" FIA plots across Oregon and Washington from 2001–2005. Each plot consisted of four 0.017 ha (7.32 m radius) subplots systematically arranged at each field grid location. On standard plots, the cover of the most abundant species was estimated on each subplot. The criterion for "most abundant" was the three species from each growth form (tree seedling, shrub, forb, or graminoid) with the greatest cover and any additional species with cover ≥3 percent. On intensive plots, cover of each vascular plant species present was estimated on each subplot. In addition, the presence or absence of species with canopy cover within 0-1.8 m above each of three 1 m^2 quadrats was recorded on each subplot (Gray and Azuma 2005). Standard plots were measured during a long sample window (April to October) by crews with general forest resource measurement skills; many graminoid species and some forbs were only identified at the generic or family level due to phenology or the lack of botanical skills. On intensive plots, understory vegetation was measured by skilled botanists during the summer growing season (June to August), with provisions for collecting voucher specimens for later identification by herbarium experts.

RESULTS

One or more non-native species were recorded on 62 percent of all sampled plots in Oregon and Washington (table 1). This percentage varied among eco-regions, from 100 percent for the Northern Basin and Range to 33 percent for the North Cascades; the latter was the only eco-region where more than half the plots had no non-native species recorded. The number of plots sampled to date was low for some eco-regions, so results are less reliable than for eco-regions with greater sample sizes. The mean percentage of species on a plot that were non-native differed by eco-region, but was less than 10 percent except for the Willamette and Blue Mountains eco-regions. The non-native proportions of summed plot-level cover generally followed the same patterns found with species richness, but suggest that in some eco-regions, cover of individual non-native species tends to be lower than cover of natives.

Assuming that each species is randomly dispersed across each subplot, it is possible to combine the cover of non-native species, remove the overlap among them, and estimate the area covered. A simpler and perhaps more

Table 1—Abundance of non-native plant species on forest land in Oregon and Washington, by eco-region (Omernik 1987)

Ecoregion	N plots sampled	Plots with non-natives (%)	Non-native percentages of total (%) Species	SE	Cover	SE
Coast Range	35	51.4	7.5	1.9	4.4	2.1
Puget Lowland	5	60.0	6.4	3.3	6.5	4.8
Willamette Valley	5	80.0	25.3	7.2	25.4	11.6
Western Cascades	41	61.0	6.1	1.3	3.8	1.7
Eastern Cascades	24	62.5	7.2	1.8	6.7	3.1
Blue Mountains	34	85.3	10.7	1.7	7.3	1.9
Northern Rockies	15	73.3	7.6	1.9	7.0	3.0
North Cascades	27	33.3	2.7	1.1	2.9	2.2
Klamath Mountains	9	55.6	5.2	1.9	0.7	0.3
N. Basin and Range	6	100.0	6.7	1.2	3.5	2.4
Total	201	62.2	7.4	0.7	5.4	0.9

Table 2—Percentage of all species that were non-native on forest land in Oregon and Washington by stand size class

Size class (DBH)	Plots (n)	Species (n)	Non-native percentage Mean	SE
<12.5 cm	26	33.2	13.8	0.98
12.5-22.9 cm	49	30.7	8.7	0.57
22.9-50.8 cm	97	33.7	6.6	0.42
>50.8 cm	29	36.3	2.0	0.37

robust method (which tends to result in lower, more conservative estimates) is to sum the individual cover of non-native species and divide by the summed cover of all species. This estimated mean cover across all intensive plots in Oregon and Washington was 5.4 percent, with a standard error of 0.87 percent (table 1). Since the area of forest land in the two states is estimated to be 21,284,000 ha, we can calculate the area covered by non-native plants as 1,153,000 ± 186,000 ha. This is the basic metric needed for national reporting of non-native plants (Anonymous 1995, Heinz Center 2002).

The percentage of species that were non-native declined with increasing stand size class (table 2). In general, stand size class is highly correlated with time since severe disturbance in this region, and the results indicate that most non-native plant species on forest land in the region are associated with recently-disturbed areas.

The most important non-native species on forest land in Oregon and Washington was *Bromus tectorum* (table 3), a species known in the region for its dramatic impacts on rangelands, and the most common non-native species east of the Cascade Mountains. However, the next two most commonly-encountered species (*Mycelis muralis* and *Tragopogaon dubius*) have not received much attention on the various state and agency lists of invasive species in the region. *Mycelis* was the most common non-native species on the west slopes of the Cascades, while *Tragopogon* was important in the Blue Mountains and mountains in northeastern Washington. Some of the common non-native species are found on several invasive species lists (e.g., *Hypericum perforatum* and *Cirsium vulgare* (Savi) Ten.), but other prevalent species are on few or no lists (e.g., *Rubus laciniatus* and *Holcus lanatus* L.).

Table 3—Non-native species found on 5 or more forest health plots, showing the number of plots the species was recorded on (out of 201), mean characteristic cover at the plot level, and the number of invasive lists the species was found on (out of 8)

Scientific name	Common name	N plots	Mean Cover	Number of Inv. lists
Bromus tectorum	cheatgrass	40	7.11	4
Mycelis muralis	wall-lettuce	27	1.17	0
Tragopogon dubius	yellow salsify	24	0.43	1
Hypericum perforatum	common St. Johnswort	21	1.73	6
Digitalis purpurea	purple foxglove	20	1.89	3
Cirsium vulgare	bull thistle	19	2.31	6
Dactylis glomerata	orchardgrass	18	1.55	2
Rumex acetosella	common sheep sorrel	18	0.43	1
Hypochaeris radicata	hairy catsear	17	3.18	3
Rubus laciniatus	cutleaf blackberry	17	2.90	0
Senecio jacobaea	stinking willie	16	1.09	7
Holcus lanatus	common velvetgrass	15	17.02	2
Rubus discolor	Himalayan blackberry	15	7.21	6
Leucanthemum vulgare	oxeye daisy	14	0.88	4
Lactuca serriola	prickly lettuce	14	0.25	2

Since the 4,169 standard plots with forest land in Oregon and Washington were sampled over long field seasons by crews with a variety of botanical skills, we examined the data and interviewed crew members to determine which species could be reliably detected. The selected species were examined to determine their distribution and their association with vegetation and climate variables using logistic regression. The distribution of two reliably-identified invasive species is illustrated in figure 1. *Bromus tectorum* (cheatgrass) was most frequently recorded in the Eastern Cascades and Blue Mountains eco-regions, but was well-distributed across the eastern areas of the two states. The frequency of *B. tectorum* was primarily associated with low annual precipitation and low tree basal area. In contrast, *Rubus discolor* Weihe & Nees (Himalaya blackberry) was well-distributed in the western parts of the two states, but was primarily associated with low elevations. Although some of these relationships were similar to those found in a portion of western Oregon (Gray 2005), this analysis described a broader range of conditions, and climate tended to be more important.

CONCLUSIONS

The results from the strategic FIA inventory on non-native invasive species in Oregon and Washington illustrate the power of having a comprehensive assessment with consistent protocols and sampling effort. The high percentages of plots with non-native species are novel data and may be somewhat surprising to policy-makers and the general public, many of whom regard the regions' forestlands as rather pristine and consider invasive species to still be an emerging or future threat. Compared to many monitoring protocols with subjective sampling approaches, the lack of bias in sample location and sampling effort provides high confidence in the applicability of the data. The data collected with the "intensive" all-species protocols can be readily summarized to address national reporting needs with appropriate estimates of confidence in the mean.

The "standard" FIA plot grid provides a much higher density of points with which to assess the distribution and abundance of selected non-native invasive species. However, it is currently not feasible to sample a large number of (or all) plant species on the standard plot grid. Several FIA regions have developed lists of invasive species that crews are trained to detect on standard plots

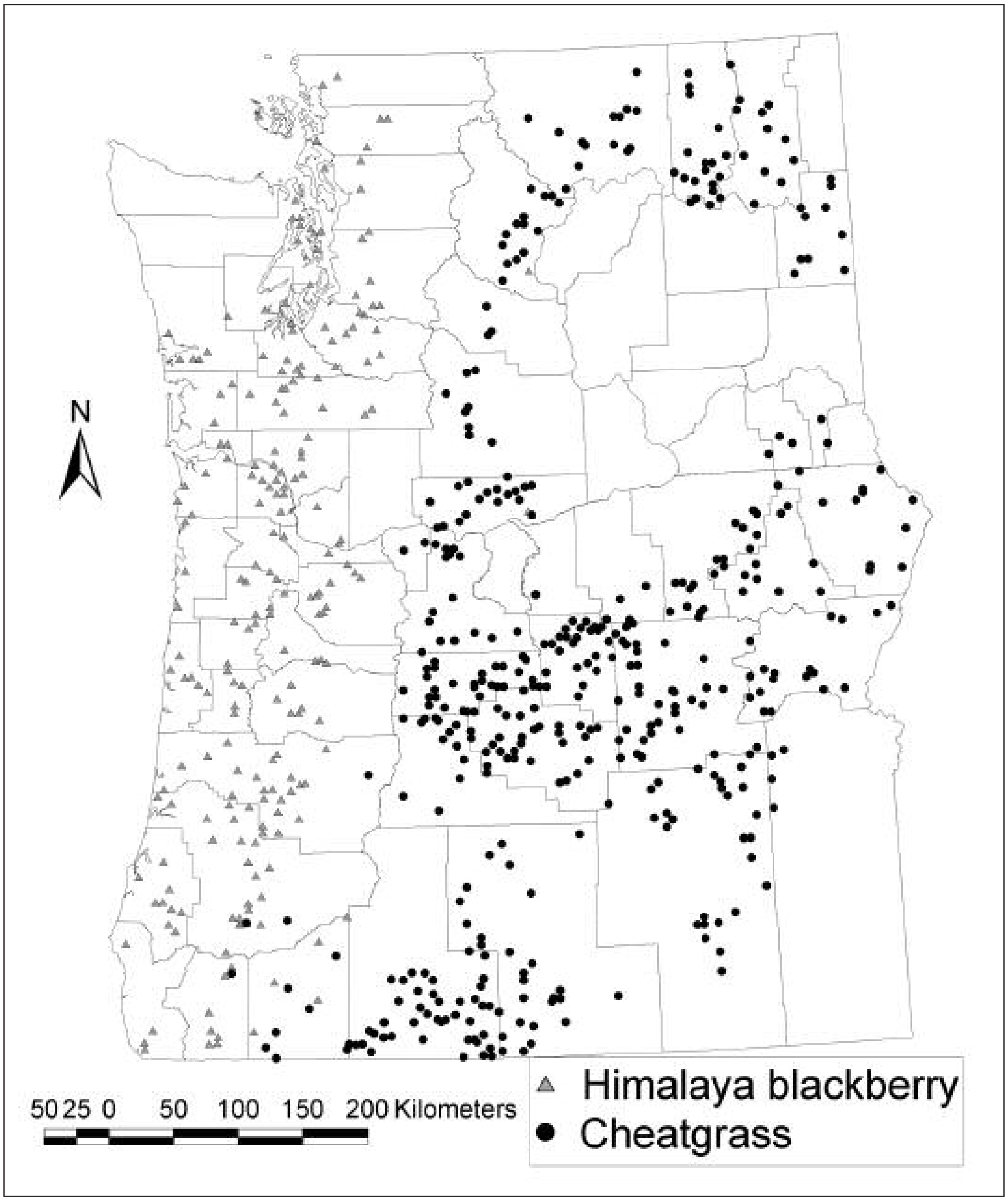

Figure 1—Distribution of the two most abundant non-native species found on standard FIA plots in Oregon and Washington, showing county boundaries.

(Rudis et al. 2005). If adopted in the Pacific states, an invasive list would need to be limited to less than 40 species and be biased towards those that are readily identifiable for much of the year. The open question to experts concerning the choice of FIA protocols is: Which is more useful, greater accuracy about the distribution of selected invasive species, or a comprehensive, lower-resolution assessment of all species (native and non-native)?

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HERBARIUM COLLECTIONS AND INVASIVE SPECIES BIOLOGY: UNDERSTANDING THE PAST, PRESENT, AND FUTURE

David E. Giblin[1], Ben Legler[2], and Richard G. Olmstead[3]

ABSTRACT

It is widely accepted that herbarium specimens have been and continue to be fundamental to understanding the biology and taxonomy of invasive plant species. Over the last 60 years, specimens from Pacific Northwest (Oregon, Washington, Idaho, Montana, British Columbia, and Alaska) herbaria have supported seminal research by several regional invasive species biologists (Ownbey 1950c, Reichard and Hamilton 1997, Novack and Mack 2001, Zika 2003). However, there remains a considerable gap between the recognized and the documented distribution of many plants considered invasive in this region.

KEYWORDS: Herbaria, invasive species, Washington, WTU.

INTRODUCTION

The University of Washington Herbarium (also known as WTU) is the largest herbarium in the Pacific Northwest and contains Washington State's most comprehensive collection of invasive plant species. There are currently over 11,800 specimens of introduced species in WTU's Pacific Northwest collections dating back to the 1880s, with 3,300 of these specimens having been added in the last ten years through a combination of efforts by individual researchers and WTU-sponsored collecting trips (fig. 1).

In the last two years, WTU botanists have made first-time collections in Washington natural areas of potentially invasive species (e.g., *Sorbus hybrida* L., *Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud.), an aggressive non-native species (*Impatiens glandulifera* Royle) not previously recorded on Mt. Baker-Snoqualmie National Forest, and a species known to be invasive in Oregon and California (*Geranium lucidum* L.). Contrary to the situation at WTU, there is an overall decline in the growth of herbaria collections throughout the U.S. (Prather et al. 2004a). This decline is compromising efforts to detect when potentially invasive species become established in the wild and the ability to assess how quickly such species may spread (Prather et al. 2004b).

Examining WTU's holdings for several well-established invasive species in the Pacific Northwest, we found substantial information gaps regarding documented occurrences and recognized distributions. For example, there are a total of four specimens of *Spartina alterniflora* Loisel. at WTU, with only one of these specimens deposited before 1994. The rapidly spreading *Buddleja davidii* Franch. is represented at WTU with a total of ten Washington State specimens from six counties, and only five of these specimens were collected prior to 2000.

DEVELOPMENT OF AN ONLINE DATABASE

The emergence of the digital age has transformed the rate and means by which invasive species data can be shared.

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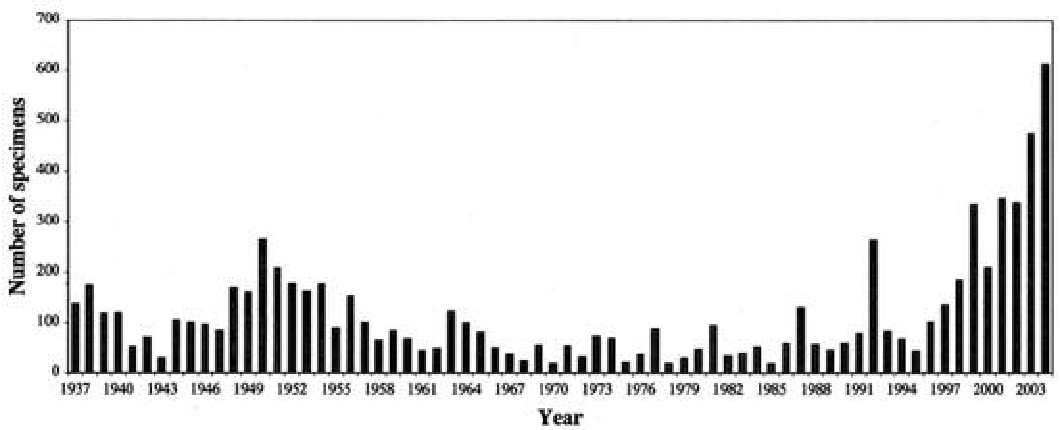

Figure 1—The number of specimens of non-native species added to the WTU vascular plant collections between 1937-2004. We chose 1937 as the beginning date because this is the year that C.L. Hitchcock, author of *Vascular Plants of the Pacific Northwest*, arrived at the University of Washington and began expanding the collection. The last year for which we have all specimens documented in the database is 2004.

Through a grant from the National Science Foundation, WTU staff have documented within a database and created online access to label information from over 150,000 specimens, as well as the ability to download these data. Ready access to herbarium specimens that reflect contemporary distributions for invasive plant species, specimen collections that are comprehensive in capturing the morphological variation of such species, and specimen label data that are readily available online are invaluable tools for academic researchers, conservation biologists, and natural resource managers interested in theoretical and applied issues associated with the biology and taxonomy of invasive plant species. We recommend that state and federal agencies provide financial support for field collecting activities that document the distribution of non-native species, that duplicate specimens from such activities be deposited at regionally significant herbaria, and that small herbaria maximize emerging databasing and data sharing opportunities so that their collections data are also available to the broadest possible audience.

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PARTNERSHIPS, EDUCATION, AND OUTREACH

Hound's-tongue (*Cynoglossum officinale*) (Lisa K. Scott)

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WEEDS CROSS BORDERS PROJECT: A CANADA – UNITED STATES COLLABORATION

Lisa K. Scott[1]

ABSTRACT

The "Weeds Cross Borders Project" is a partnership of land managers, agencies and regional invasive plant committees in the greater Okanagan region of Canada and the United States. Partners include the South Okanagan-Similkameen Invasive Plant Society, Okanogan County Noxious Weed Control Board, Boundary Weed Management Committee, Ferry County Noxious Weed Control Board, WSU Extension Ferry County, B.C. Ministry of Transportation and Washington State Department of Transportation. The project facilitated cooperation and improved coordination of the laws, regulations and policies that have differed in the past. A Cooperative Weed Management Area was established to help prevent and control non-native invasive plant species that have an adverse effect on native plant communities, wildlife habitat and agricultural lands. The project provides an integrated and coordinated approach to invasive plant management, sharing resources for education, training, inventory and control. Invasive plants do not recognize our political boundaries, but freely travel our waterways, railways and highways, dispersing their seed along the way. Coordinating treatment and education across our borders is necessary to effectively control invasive plants in the long term over the entire geographic area. In 2004 and 2005, priority weeds were inventoried and mapped along both sides of the border. Treatments of selected weeds included seeding, hand-pulling, cutting, biological control and herbicide applications. With public education deemed an essential component of the project, the partners developed an education/outreach program to effectively communicate invasive plant management issues, including the production of posters, press releases and a Cross Borders flyer that was distributed to thousands of landowners on both sides of the border.

KEYWORDS: Invasive plant management, inventory, monitoring, treatment, public education, international.

INTRODUCTION

Invasive plants are a serious threat to the economy and biodiversity of the greater Okanagan Region of British Columbia and Washington State. Invasive plants threaten both species and habitats at risk. Non-native weeds are invading new habitats at a rate of 12–14 percent per year, in the absence of efforts to contain their spread.

Invasive plants do not recognize political boundaries. They freely travel our waterways, railways and highways, dispersing their seed along the way. Coordinating treatment and education across borders is necessary to effectively control invasive plants in the long term over an entire geographic area. As a result of this identified need, the "Weeds Cross Borders Project" was established in 2004. The project is a partnership of land managers, agencies and regional invasive plant committees in the greater Okanagan region of Canada and the United States. Partners include the South Okanagan-Similkameen Invasive Plant Society, Okanogan County Noxious Weed Control Board, Boundary Weed Management Committee, Ferry County Noxious Weed

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Table 1—Target weed species with legal corresponding designations or control requirements in Washington State and British Columbia

Common Name	Latin Name	WA Designation	B.C. Designation
Leafy spurge	*Euphorbia esula*	Class B Designate	Provincially Noxious
Meadow hawkweed	*Hieracium pratens*	New Invader	Not categorized
Musk (nodding) thistle	*Carduus nutans*	Class B Designate	Not categorized
Orange hawkweed	*Hieracium aurantiacum*	New Invader	Regionally Noxious – Bulkley-Nechako, Cariboo, Central Kootenay, Columbia-Shuswap, East Kootenay, Thompson-Nicola
Puncturevine	*Tribulus terrestris*	Class B Designate	Regionally Noxious – Okanagan-Similkameen
Purple loosestrife	*Lythrum salicaria*	Class B Designate	Not categorized
Wild four o'clock	*Mirabilis nyctaginea*	Class A Designate	Not categorized

Class A Designate – top priority, their removal is completed free of charge by the Okanogan County Weed Board.

Class B Designate - mandatory control is required to stop seed production.

The B.C. Weed Control Act imposes a duty on all land occupiers to prevent the spread of designated noxious plants. Provincially Noxious weeds are classed as noxious within all regions of B.C. Regionally Noxious weeds are classed as noxious within the boundaries of the corresponding regional districts.

Control Board, WSU Extension Ferry County, B.C. Ministry of Transportation and Washington State Department of Transportation. Within Canada the project covers the jurisdictions of the Regional District Okanagan-Similkameen and Regional District Kootenay Boundary. Within the U.S., the project area includes Ferry County and Okanogan County. The entire project area is referred to as the Weeds Cross Borders Coordinated Weed Management Area.

PROJECT ACTIVITIES

Target invasive plant species were identified within each jurisdiction. Table 1 outlines the target species and lists the different respective legal designations for Washington State and British Columbia. As part of the cooperative agreement, each jurisdiction agreed to match designations for target weed species. For example, wild four o'clock *Mirabilis nyctaginea* (Michx.) MacM. is currently not categorized in British Columbia, yet it is a Class A designate in Washington State. This means that in WA, it is a high priority species and eradication is required by the Okanogan County Weed Board. As a consequence of collaboration, the Canadian partners agreed to control all identified infestations of wild four o'clock occurring within the Okanagan and Boundary Regions adjacent to the U.S. Border. Similarly, the status of puncturevine *Tribulus terrestris* L. was elevated in the U.S. to match the higher Canadian designation. These examples of changes to existing weed management approaches ensured that the same level of control was being achieved on both sides of the border for each of the respective target weed species.

Infestations of target invasive plants were inventoried and mapped along all State/Provincial Highways, as well as identified secondary or county roads. Mapping was also conducted along connecting waterways, including Lake Osoyoos and Kettle River, and along the Canadian – United States Border. The inventory was necessary to identify infestations for control and to provide the baseline data necessary to monitor and evaluate treatment effectiveness.

Control activities were conducted using an integrated approach of prevention, in combination with physical, chemical and biological control options. For both the Canadian and U.S. infestations, plants were treated with a combination of mowing, site-specific herbicide applications, hand pulling, re-vegetation and biological control agent releases.

Education and outreach were also identified as a priority action by each of the project partners. General invasive plant information as well as species-specific resources were produced and distributed throughout the Weed Management Area. These resources included posters, press releases, bulletins, calendars and flyers. These resources were distributed by each of the project partners at community events and were posted at libraries, municipal offices, government agencies, bike shops and community bulletin boards. The flyers were sent to over 20,000 landowners living within the Weed Management Area.

The issue of cross border invasive plant management was also raised with Canadian and U.S. politicians. Legislative tours were conducted in 2004 and 2005, highlighting the target species, the concerns surrounding their management and the importance for continued and increased financial support.

FUTURE OUTLOOK

The resources provided through the Cross Borders Project allowed partners to more effectively manage weeds in a cooperative fashion. The project provided the partners with an opportunity to improve individual weed management programs through information exchange, education and training, coordination of inventory and control efforts, and sharing of resources when appropriate. This cooperative project is a unique British Columbia-Washington endeavor that sets an example for other agencies and other jurisdictions to follow. With the partnerships established, we look forward to continuing this program into the future. With limited funding, the partnerships allow each agency to make the most of existing budgets and control projects, because weeds know no boundaries.

ACKNOWLEDGMENTS

Many people contributed to the successful completion of the past three years of cross border weed management. These individuals represent a wide variety of affiliations and backgrounds.

Significant financial contributions were provided by the U.S. Federal Highway Administration, B.C. Ministry of Transportation and the (B.C.) Inter-Ministry Invasive Plant Committee.

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THE ST. LOUIS CODES OF CONDUCT: PROVIDING A FRAMEWORK TO PREVENT INVASIONS FROM HORTICULTURE

Sarah H. Reichard[1]

ABSTRACT

Invasive plants are a serious problem affecting our ability to preserve native organisms, ecosystems, and functions. Many invasive plants are introduced through horticultural channels. In 2001 a group of people involved in professional horticulture developed the St. Louis Codes of Conduct, a voluntary framework to assess how professional activities affect the introduction and spread of invasive plants. At the University of Washington Botanic Gardens we have implemented the codes of conduct. This paper reviews the codes for botanic gardens and how the staff addressed them. This included revising the collections policy, removing plants, developing partnerships, and engaging the administration of the University of Washington.

KEYWORDS: Invasive plants, horticulture, codes of conduct.

INTRODUCTION

Invasive plants have emerged as a leading threat to the conservation of species, threatening endangered species (Wilcove et al. 1998). They are known to alter ecosystem processes such as nutrient cycling (Vitousek et al. 1987) and those alterations may persist even after removal of the species (Dougherty and Reichard 2004). Invasive species have substantial economic impact as well. Estimates of the economic costs associated with invasive species (plants and animals) were conservatively estimated to be $137 billion annually in 2000 (Pimental et al. 2000) and the federal government reported spending more than $631 million on invasives species activities in fiscal year 2000 (GAO 2000). Seven states were surveyed and reported spending a total of more than $232 million for the same fiscal year (GAO 2000).

Populations of invasive species already present are often controlled using various methods, but increasing attention is being given to preventing their introduction and spread. Prevention may be achieved through risk assessment, either at time of introduction or at first detection, as well as by determining possible pathways and implementing ways to mitigate those pathways. In some cases, educating those involved may help to alleviate the movement of species through the pathway by alerting them to the problem and providing suggestions for solutions.

Invasive plants are often introduced and widely sold as landscape plants. Estimates are that more than 60 percent of all invasive species and over 80 percent of woody invasive species were introduced through horticulture (Reichard 1997). Those introducing the plants are usually unaware of their potential to spread and have a negative impact to native plant and ecosystems and they do not bear the costs asso-ciated with controlling them.

The National Invasive Species Council produced a National Management Plan (NMP) that was signed by then-President William Clinton in 2001. The NMP includes a chapter on prevention; action item 15 states the Federal agencies will develop screening systems and other comparable management measures, possibly including codes of conduct (National Invasive Species Council 2001).

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Codes of conduct, also called codes of practice or codes of ethics, provides a formal statement of values and/or best management practices. Many businesses and industries establish codes of conduct to communicate their standards to the world. Codes of conduct also make an excellent framework for education about issues and communication between the industry and others.

In 2001 the Missouri Botanical Garden in St. Louis, in collaboration with the Royal Botanic Garden at Kew, England convened a workshop to develop codes of conduct for horticulture professionals, as well as amateurs. Participants were invited from five categories: retail and wholesale nurseries, botanic gardens and arboreta, landscape architects, government agencies, and the gardening public (Reichard 2004).

Over three days the participants developed mutually agreed upon Findings and Guiding Principles (table 1). These provided the foundation for the disciplinary codes of conduct (Reichard 2004). The codes of conduct had substantial overlap among the disciplines, e.g., assess risk of new introductions, know current invasives in the region, use and promote alternative species, and provide leadership and educational opportunities for members. The codes differed in some of the areas more specific to the disciplines, such as botanic gardens examining their collections policy, a policy that would not be found in the other disciplines. The government also addressed their role in early detection of new species and seeking international cooperation, and acknowledged their eventual need to evaluate the effectiveness of the codes of conduct. The codes for each discipline may be found at http://www.centerforplantconservation.org/invasives/codesN.html.

In 2003 I gathered a group of graduate students interested in implementing the codes of conduct at the University of Washington Botanic Garden (UWBG), made up of the Washington Park Arboretum (WPA) and the Center for Urban Horticulture, using the codes for botanic gardens. When considering the first code, to perform an assessment of all of the policies of the institution, however, we decided that our institution was not the UWBG, but the University of Washington. This somewhat altered our process and we proceeded to address all of the public garden codes with the University in mind. Below I list the codes of conduct for botanic gardens and arboreta and describe how we addressed them for the UWBG and, where appropriate, the UW.

Codes of Conduct for Botanic Gardens and Arboreta

1. Conduct an institution-wide review examining all departments and activities that provide opportunities to stem the proliferation of invasive species and inform visitors. For example, review or write a collections policy that addresses this issue; examine such activities as seed sales, plant sales, book store offerings, wreath-making workshops, etc.

As discussed, we chose to review the University of Washington rather than just the botanic gardens. The gra-duate students met with the UW Campus Landscape Advisory Committee to present the codes to them and discuss concerns. There was concern that implementation would increase costs in a very tight budget situation, but most apprehension was easily addressed. It was decided an invasive species policy would be developed for campus, including the various properties that the UW owns beyond the main campus, such as the Friday Harbor Marine Laboratories (FHML) in the San Juan Islands. Thus, another class worked collaboratively with FHML to develop a vegetation management plan to help them manage existing invasive species and to prevent the introduction of new ones. While it was outside our expertise, we also discussed with them their policies to prevent release of marine organisms into Puget Sound via the laboratories. It is intended that future classes will develop plans for other UW properties.

Public gardens typically have a collections policy, which guides how collections will be acquired, used, and cared for. At the UWBG we revised our collections policy to ensure that each aspect was compliant with the Codes of Conduct. We continue to discover new issues that should be included in the collections policy, such as introduction of soil borne seeds and organisms through plants donated by individuals, so this will be an on-going activity.

Table 1—The St. Louis Declaration

Findings	•	People are major dispersers of plants. The magnitude of this dispersal is unprecedented and has allowed dispersal of species that manifest aggressive traits in new areas.
	•	Plant introduction and improvement are the foundation of modern agriculture and horticulture, yielding diversity to our supply of plants used for food, forestry, landscapes and gardens, medicinal and other purposes.
	•	A small proportion of introduced plant species become invasive and cause unwanted impacts to natural systems and biological diversity as well as economies, recreation, and health.
	•	Plant species can be invasive in some regions, but not in others. The impacts of invasive plant species can occur at times and places far removed from the site of introduction.
Guiding Principles (a.k.a. "The St. Louis Six")	1.	Plant introduction should be pursued in a manner that both acknowledges and minimizes unintended harm.
	2.	Efforts to address invasive plant species prevention and management should be implemented consistent with national goals or standards, while considering regional differences to the fullest extent possible.
	3.	Prevention and early detection are the most cost-effective techniques that can be used against invasive plants.
	4.	Research, public education and professional training are essential to more fully understanding the invasive plant issue and positively affecting consumer demand, proper plant use, development of non-invasive alternatives, and other solutions.
	5.	Individuals from many fields must come together to undertake a broad-based and collaborative effort to address the challenge, including leaders in horticulture, retail and wholesale nurseries, weed science, ecology, conservation groups, botanical gardens, garden clubs, garden writers, educational institutions, landscape architects, foundations and government.
	6.	A successful invasive plant species strategy will make use of all available tools including voluntary codes of conduct, best management practices, and appropriate regulation. Codes of conduct for specific communities of interest are an essential first step in that they encourage voluntary initiative, foster information exchange, and minimize the expense of regulation.

2. Avoid introducing invasive plants by establishing an invasive plant assessment procedure. Predictive risk assessments are desirable, and should also include responsible monitoring on the garden site or through partnerships with other institutions. Institutions should be aware of both direct and indirect effects of plant introduction, such as biological interference in gene flow, disruption of pollinator relationships, etc.

I have studied the biology of invasive plants and worked on predictive methods, including methods that are used by other public gardens and nurseries (Reichard 1997, Reichard and Hamilton 1997, Reichard 2001). These methods combine aspects of species biology with invasive history elsewhere to suggest if a species is likely to become invasive, not likely, or if further evaluation is needed. I assess all species proposed for addition to the collection at UWBG, but main campus has its own selection criteria and oversight committee, the Campus Landscape Advisory Committee. The campus landscape architect, sometimes working with an outside firm, suggests plants, which are then approved by the committee.

3. Consider removing invasive species from plant collections. If a decision is made to retain an

invasive plant, ensure its control and provide strong interpretation to the public explaining the risk and its function in the garden.

As part of a regional project I have been working with the Washington State Nursery and Landscape Association to remove five species invasive in maritime Washington from commercial trade. These include *Buddleja davidii* (butterfly bush), *Ilex aquifolium* (English holly), *Iris pseudacorus* (yellow flag iris), *Foeniculum vulgare* (common garden fennel), and selected cultivated varieties of *Hedera hibernica*/*H. helix* (English and Atlantic ivies). The UWBG therefore decided to remove these species from the collection as well. There are no *Iris* or *Foeniculum* in the collection, nor are the invasive cultivars of *Hedera* in the WPA, except as invasive populations. All *B. davidii* plants were removed. The English holly, however, required a more nuanced approach. The WPA has an internationally recognized collection of hollies and English holly is an important species in the genus. The curatorial decision was made to remove all but one plant and to provide interpretation about its invasiveness. The single plant will be enclosed in a structure designed to exclude birds, the dispersers of the fruits. This mirrors a much earlier decision to leave the less invasive *Sorbus aucuparia* in the important *Sorbus* collection, but to interpret its attractiveness to birds and subsequent invasion.

4. Seek to control harmful invasive species in natural areas managed by the UWBG and assist others in controlling them on their property, when possible.

The UWBG manages the Union Bay Natural Area which is 90 acres including grassland, extensive lake shoreline, and some deciduous forest. It is one of the largest open areas in the city of Seattle and contains a large percentage of invasive species. One part-time employee works mostly on invasive species control, with the occasional assistance of other employees. University of Washington restoration classes have used it as laboratory space for restoration for about 15 years. In addition, the UWBG is the home of the Restoration Ecology Network, which partners university students with restoration projects throughout the region (Gold et al. 2006).

5. Promote non-invasive alternative plants or, when possible, help develop non-invasive alternatives through plant selection or breeding.

Working with members of the Washington State Nursery and Landscape Association (WSNLA) and the Washington State Noxious Weed Board (WSNWB), the UWBG and other environmental groups developed alternatives to 16 species that are invasive in western Washington and sold in the landscape trade. We designed an attractive 32 page booklet that pictured the invader and described why it is a problem, along with photographs and descriptions of safe alternatives (http://plonenw.onenw.org/InvasiveSpeciesCoalition/GardenPlants/). This required understanding why consumers wanted these species and then finding alternatives that met all the various needs, although not necessarily in one species. The initial printing of 26,000 booklets was given out through flower shows, noxious weed boards, master gardeners, nurseries, libraries, and other methods. Its success has lead to a second printing and to development of a similar booklet for eastern Washington species.

6. If your institution participates in seed or plant distribution, including through *Index Seminum*, do not distribute known invasive plants except for bona-fide research purposes, and consider the con-sequences of distribution outside your bio-geographic region. Consider a statement of caution attached to species that appear to be potentially invasive but have not been fully evaluated.

Index seminum, which translates as “seed list,” is an informal seed exchange between many public gardens. Not all gardens participate and a few of those that do have policies dictating that they trade seed only for research or within their bioregion. The UWBG participates, but mostly lists wild-collected seeds of species native to the Pacific Northwest. Recognizing that some species from this region, such as *Pseudotsuga menziesii* Mirb.el (Franco), Douglas-fir, are invasive when introduced to others parts of the world, such species are identified and marked with an asterisk. The asterisk leads to the following statement: "The Washington Park Arboretum is concerned about the impact of alien plant introductions on local native plant populations. Those species followed by an asterisk have been reported to naturalize in some regions of the world. It is assumed that institutions or individuals receiving seed will take appropriate steps to evaluate the invasive potential of all plant introductions."

7. Increase public awareness about invasive plants. Inform why they are a problem, including the origin, mechanisms of harm, and need for prevention and control. Work with the local nursery and seed industries to assist the public in environmentally safe gardening and sales. Horticulture education programs, such as those at universities, should also be included in education and outreach efforts. Encourage the public to evaluate what they do in their own practices and gardens.

As previously discussed, I have worked with the WSNLA to teach their members about invasive species and remove some from sale. In addition, we offer adult education classes in weed identification to amateur and professional horticulturists. I teach a landscape plant identification class, required for landscape architecture undergraduates, in which I discuss the invasiveness of the species covered and I teach another class entitled the "Biology, Ecology, and Management of Invasive Plants." I also give presentations to garden clubs and other community groups.

8. Participate in developing, implementing, or supporting national, regional, or local early warning systems for immediate reporting and control. Participate also in the creation of regional lists of concern.

The UWBG includes the Otis Douglas Hyde Herbarium, a collection of pressed and dried plant specimens. For several years it has been developing a collection of area invasive species and houses the collection of the Washington State Noxious Weed Board. Many duplicates of the invasive species in the collection have been traded with other institutions to increase the number of specimens and to include species that may be found in other parts of North America, but are not currently found here. This will facilitate confirmation of identity should the species be found here. In addition, we encourage members of the public to bring in unknown plants for identification. We notify the WSNWB of anything that appears to be potentially invasive. In addition, I chaired a committee which developed a prioritized list of invasive plants known in Washington and Oregon as of 1997. This list needs updating.

9. Botanical gardens should try to become informed about invasiveness of their species in other biogeographic regions, and this information should be compiled and shared in a manner accessible to all.

As discussed in code number 6, the UWBG does include information about the invasiveness of our native species when we participate in the *Index Seminum* program. We do not publicize it otherwise.

10. Become partners with other organizations in the management of harmful invasive species.

The Restoration Ecology Network (see code number 4) has been active with a wide array of agencies and organizations, managing invasive species and educating students and the public. In the past six years they have worked on over 25 unique projects, partnering with city parks, colleges and universities, private interests, and citizen's groups.

11. Follow all laws on importation, exportation, quarantine, and distribution of plant materials across political boundaries, including foreign countries. Be sensitive to conventions and treaties that deal with this issue, and encourage affiliated organizations (plant societies, garden clubs, etc.) to do the same.

This is, of course, something that is always done. When seed is imported for research, through *Index Seminum*, or through other sources, all permits are obtained. When appropriate, permission from the exporting country is sought.

CONCLUSION

Ultimately the best solution for dealing with invasive plants with horticultural origins is likely increased regulation regarding importation and sale. Other countries have successfully implemented such restrictive regulations (Pheloung 2001). However, voluntary Codes of Conduct serve an important role in education about invasive species and provide a framework for individuals, businesses, organizations, and agencies to assess their own actions. We also found it was a useful tool to engage our university administrators in a dialogue about activities on a wide scale at the institution. The St. Louis Declaration provides Codes of Conduct for the five groups invited in that endeavor but efforts are also underway to develop such codes for the pet industry, specifically for water gardening (J. Reaser, Pet Industry Joint Advisory Committee). Learning from the experiences of developing the St. Louis Declarations (Reichard 2004), other industries and interest groups may also want to develop codes of conduct.

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POLICIES TO REDUCE THE RISK OF INVASIVE PLANT INTRODUCTIONS VIA HORTICULTURAL TRADE: STAKEHOLDER PERCEPTIONS AND PREFERENCES

Arianne Ransom-Hodges[1]

ABSTRACT

Invasive alien plant species cause both economic losses and ecological damages. However, many potentially invasive plant species are deliberately introduced for economic benefit, such as for horticultural trade, despite the risks associated with them. Nonetheless, prevailing policies aimed at addressing the invasive alien plant problem fail to explicitly consider both the role of the horticulture industry as a cause of the problem and the substantial revenues generated through the introduction and sale of ornamental plants. Here, I present a range of credible policy options for reducing the risk of invasive plant introductions via horticultural trade. In addition, I outline how my graduate research will discern stakeholder perceptions of the invasive plant problem while determining and explaining stakeholder preferences with respect to the alternative policy interventions.

KEYWORDS: Horticulture, invasive plants, policy alternatives, risk, North America.

INTRODUCTION

Invasive alien plant species are known to cause both economic losses and ecological damages (Pimentel et al. 2005, Wilcove et al. 1998). However, the introduction of a non-native species can be simultaneously classified as destructive by one segment of society and desirable by another (Reichard 2005). Indeed, many potentially invasive plant species are deliberately introduced for economic benefit despite the risks associated with them (Haber 2002). Notably, ornamental species comprise the vast majority of invasive plants in many countries (Baskin 2002). Therefore, the horticulture industry is the most significant pathway for the intentional introduction of invasive alien plants.

Nonetheless, prevailing policies aimed at tackling the invasive alien plant problem in North America fail to explicitly address its horticultural dimension. Specifically, conventional policies fail to explicitly consider both the role of the horticulture industry as a cause of the problem and the substantial revenues generated via the introduction and sale of ornamental plants (Simberloff et al. 2005, Knowler and Barbier 2005, Perrings et al. 2002). Although new government strategies are being devised and implemented in Canada and the United States, economic benefits derived from the horticultural use of alien plant species continue to be overlooked.

RESEARCH OBJECTIVES

The purpose of my research is to identify policy options that address the problem of invasive alien plant species and assess their acceptability to stakeholder groups. The specific objectives of my research are thus to:

- identify plausible policy options to address the introduction of invasive alien plant species via horticultural trade
- discern stakeholder perceptions of the invasive plant problem

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- determine stakeholder preferences with respect to various policy options
- determine stakeholder perceptions of key concerns/ obstacles with respect to policy development (e.g., potential costs, institutional problems, unfair distribution of cost/benefits, etc.)
- identify determinants of stakeholder preferences (e.g., individual background, geographic location, etc.).

METHODOLOGY

I will collect data through the use of a web-based survey of stakeholders belonging to the following groups: professional horticulturists, amateur gardeners, agriculturalists, park managers and staff, invasive plant experts, and naturalists.

After the completion of a pilot test, the survey will be launched in October 2006. The study sample will consist of stakeholders residing in four Canadian provinces (British Columbia, Saskatchewan, Ontario, and New Brunswick) and five American states (California, Montana, Ohio, Connecticut, and Florida) (fig. 1). The selection of the nine key jurisdictions listed above ensures that stakeholders from across North America will be surveyed.

Through the survey, study participants will be asked to select the stakeholder category (e.g., professional horticulturist, amateur gardener, agriculturalist, etc.) that corresponds to the capacity in which they are confronted most by the alien invasive plant problem. Furthermore, respondents will disclose their perceptions of the problem and preferences among alternative strategies aimed at addressing the problem. Participants will also provide general socio-demographic information. In order to assess stakeholder preferences for the different policy options, survey respondents will rank five alternative policies from most to least preferred. Furthermore, a list of considerations will be provided and participants will be asked to identify the consideration that most influenced the order in which they ranked the policy options. In order to prevent arbitrary selections from the list of considerations, a category labeled ‘other’ is included.

Once the data are collected, a contingent ranking approach will be used to analyze stakeholder preferences for various policy options. A multinomial LOGIT model will estimate the probabilities of observing potential rankings. The model will be used to explain how changes in sample attributes, including demographic characteristics and stakeholder group membership, might affect predicted probabilities.

Policy Options

Five plausible policy options have been identified from a review of the literature. By focusing on three key considerations for designing policies aimed at tackling the horticultural dimension of the invasive plant problem, these policies were subsequently simplified such that they can be easily described and presented to respondents (table 1). The three main considerations are: (1) the method used to determine which plant species will be targeted by the policy, (2) the approach used to limit the introduction and dispersal of the specified plant species, and (3) the way the policy will be implemented and enforced.

The stakeholder survey outlines two methods for determining which plant species will be considered invasive. The first is black listing - the listing of all non-native plant species known to be invasive in a given region. As such, only species that have already invaded will be listed. The second approach, screening, consists of assessing the likelihood that newly imported non-native plant species will become invasive. The screening approach results in policies that only target species that have a high likelihood of invasion.

Three approaches for limiting the introduction and dispersal of plant species considered invasive are described in the survey. Ban/quarantine, where the import and sale of all plant species that are considered invasive is completely prohibited, is the first approach. The second, a variable tax, involves imposing a variable monetary charge on the sale of all newly imported non-native plant species. The tax rate is dependent on the likelihood of invasion of a species. Lastly, a fixed environmental fee can be applied such that a fixed monetary charge is imposed on the sale of all non-native plant species.

Finally, respondents will be presented two ways to implement and enforce policies. The first is a mandatory

Figure 1—Map of jurisdictions where study will be conducted.

approach by which polices are implemented and enforced by the government. The second approach consists of voluntary self-regulation, in which the horticulture industry is responsible for implementation and enforcement of the policy (e.g., by establishing voluntary codes of conduct).

The first two considerations can be combined to produce policies governing the import and sale of non-native species. The last consideration specifies how these policies are implemented and enforced. For the purposes of the survey, five credible policy options are devised by combining all three considerations (table 1).

Table 1—Policy options presented to survey respondents

	Policy options				
	Option 1	**Option 2**	**Option 3**	**Option 4**	**Option 5**
Import & sale	**Black list** and **ban** all species listed	**Screen** and **ban** species with a high likelihood of invasion	**Screen** and **ban** species with a high likelihood of invasion	**Screen** and **variable tax**	**Fixed environmental fee**
Implement & enforce	**Mandatory**	**Mandatory**	**Voluntary**	**Mandatory**	**Mandatory**

POTENTIAL IMPLICATIONS

The proposed research will support the development of policies to address the intentional introduction of invasive plant species by the horticulture industry.

While some of the policy options presented in the survey represent existing policies (Option 1 - black listing) or new strategies currently being considered by governments in Canada and the United States (Option 2 - risk assessment), others represent less familiar approaches. Option 3 corresponds to industry self-regulation, Option 4 mirrors an optimal pollution tax (Knowler and Barbier 2005), and Option 5 characterizes an environmental charge. As such, my research will determine the acceptability of novel policy approaches as compared to conventional policy options. Importantly, the study will explore preferences for incentive-based policies that consider both the benefits and risks associated with the import and sale of non-native plants.

Furthermore, my research will provide information about how different stakeholder groups perceive the invasive alien plant problem. Thus, the study may potentially expose points of convergence between different stakeholder groups with respect to preferences for the various policy options. Thus, this study may help decision makers to isolate policies with high acceptability across many segments of society.

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