Management Strategies for Invasive Plants in Pacific Northwest Prairies, Savannas, and Oak Woodlands

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Abstract

Invasion by non-native plant species is one of the greatest threats to prairie, savanna, and oak woodland habitats of the Willamette Valley-Puget Trough-Georgia Basin (WPG) ecoregion. Invasive plants can modify the diversity, structure, and function of natural habitats. Effects from non-native invasions have contributed to the decline of many native species found on Pacific Northwest prairie and oak habitats. Even with aggressive management, these unique habitats are severely impacted by non-native plant invasions. Without management, native species diversity will continue to decline rapidly. Here we provide a list of invasive plants that have extensive detrimental impacts on prairies, savannas, and oak woodlands throughout the ecoregion as a resource for land managers. We provide technical descriptions for the most highly invasive shrubs, grasses, and forbs, current best management practices, and an outlook for the future. When available, we document results from experimental trials. Much of the information presented is based on field observations from experienced land managers. Invasive plants will continue to be a management priority in the WPG for the foreseeable future. Working cooperatively from an ecoregional perspective to track occurrence, develop and implement effective management, and monitor progress is the best platform for successful restoration of the prairies, savannas, and oak woodlands in the WPG ecoregion.

Introduction

Prior to Euro-American settlement, bunchgrass dominated prairies, savannas, and oak woodlands occurred throughout much of the Willamette Valley-Puget Trough-Georgia Basin (WPG) ecoregion. These habitats were largely maintained by anthropogenic fires that stymied encroaching trees and shrubs and stimulated growth of important plants used for food and medicine (Turner 1999). A unique assemblage of plant and animal species occurs primarily in prairie and oak habitats, and many are threatened with regional extirpation or extinction. Population declines are due in part to the reduction of available habitat and the continual degradation of what remains (Lea 2006). Habitat loss to agricultural conversion, development pressure in the rural-urban interface, and expansion of conifer forest are among the significant threats facing prairie and oak habitats (Floberg et al. 2004, ODFW 2005, WDFW 2006, Lilley and Vellend 2009). Another primary biological threat to WPG prairies and oak habitats, even those that are protected from conversion, is the establishment of invasive non-native species (INS), which can modify the composition and structure of the landscape, and displacing native plants and animals (ODFW 2005, WDFW 2006, Polster et al. 2006, Severns 2008, Lilley and Vellend 2009). Therefore, aggressive management of INS is a high priority for managers of prairie and oak habitats in the WPG.

The purpose of this paper is to document the current state of knowledge for managing key INS on protected prairie and oak habitats that occur within the WPG. This ecoregional perspective provides a broad picture of challenges that land managers face now and in the future. This paper represents the current knowledge of management techniques from experienced land managers who interact with selected INS, and is intended as a reference and tool to aid other managers who may deal with these and similar species. We review treatment methods for selected INS using published and unpublished reports, as well as first-hand experience. Table 1 provides a list of 108 INS that occur in

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TABLE 1. Invasive non-native species (INS) of existing or potential ecological importance in prairie, savanna, and oak woodland habitats within the Willamette Valley-Puget Trough-Georgia Basin ecoregion. "**R**" indicates rhizomatous species. For each state/province column, "Y" indicates taxa that are present, "N" indicates taxa are not known to be present, and "*" indicates that specific management targets exist within that state/province. OR=Oregon, WA=Washington, BC=British Columbia.

Latin Name	Common Name	OR	WA	BC
Annual Grasses				
Aira caryophyllea	silver hairgrass	Y	Y	Y
Aira praecox	little hairgrass	Y	Y	Y*
Anthoxanthum aristatum	annual vernal grass	Y	Y	Y
Bromus diandrus var. *rigidus (B. rigidus)*	ripgut brome	Y	Y	Y*
Bromus hordeaceus	soft brome	Y	Y	Y*
Bromus sterilis	poverty brome	Y	Y	Y*
Cynosurus echinatus	bristly dogstail grass, hedgehog dogtail	Y	Y	Y*
Poa annua	annual bluegrass	Y	Y	Y*
Taeniatherum caput-medusae	medusahead wildrye	Y*	N	N
Vulpia bromoides (Festuca bromoides)	rattail fescue, brome fescue	Y	Y*	Y*
Perennial Grasses				
Agrostis capillaris (**R**)	colonial bentgrass	Y	Y	Y*
Agrostis stolonifera (**R**)	creeping bentgrass	Y	Y	Y*
Alopecurus pratensis	meadow foxtail	Y	Y	Y
Anthoxanthum odoratum	sweet vernalgrass	Y	Y*	Y*
Arrhenatherum elatius	tall oatgrass	Y*	Y*	Y
Brachypodium sylvaticum	false-brome	Y*	Y	Y
Bromus inermis (**R**)	smooth brome	Y	Y	Y
Cynosurus cristatus	crested dogtail	Y	Y	Y
Dacytylis glomerata	orchard grass	Y	Y	Y*
Elymus repens (**R**) *(Agropyron repens)*	quack grass	Y	Y	Y
Glyceria declinata	low mannagrass	Y*	N	Y
Holcus lanatus	velvetgrass	Y	Y	Y
Holcus mollis (**R**)	creeping velvetgrass	Y*	Y	Y
Juncus marginatus (**R**)	grass leaved rush	Y	N	Y
Lolium perenne (**R**)	perennial ryegrass	Y	Y	Y*
Luzula campestris (s.s.)	field woodrush	Y	Y	Y
Phalaris aquatica	harding grass	Y*	N	N
Phalaris arundinacea (**R**)	reed canarygrass	Y*	Y*	Y
Phleum pratense	common timothy	Y	Y*	Y
Poa bulbosa	bulbous bluegrass	Y	Y*	Y
Poa compressa (**R**)	Canada bluegrass	Y	Y	Y*
Poa pratensis (**R**)	Kentucky bluegrass	Y	Y	Y*
Schedonorus arundinaceus (**R**) *(Festuca arundinacea)*	tall fescue	Y*	Y	Y
Annual/Biennial Forbs				
Alliaria petiolata	garlic mustard	Y*	N	Y*
Anchusa arvensis	small bugloss	Y	N	Y
Anthriscus caucalis	bur chervil	Y	Y	Y
Anthriscus sylvestris	wild chervil	Y	Y	Y
Carduus pycnocephalus	Italian thistle	Y*	Y	N
Cerastium glomeratum	sticky chickweed	Y	Y	Y
Crepis capillaris	smooth hawksbeard	Y	Y	Y
Daucus carota	Queen Anne's lace	Y*	Y	Y
Dipsacus fullonum (Dipsacus sylvestris)	teasel	Y*	Y*	Y
Geranuim dissectum	cutleaf geranium	Y	Y	Y
Geranium lucidum	shining geranium	Y*	Y*	N
Geranium molle	dovefoot geranium	Y	Y	Y*
Lapsana communis	nipplewort	Y	Y	Y
Lathyrus aphaca	yellow vetching	Y	N	N
Leucanthemum vulgare (Chrysanthemum leucanthemum)	ox-eye daisy	Y*	Y*	Y*
Linum bienne (Linum angustifolium)	pale flax	Y	N	Y
Parentucellia viscosa	yellow glandweed	Y	Y	Y
Senecio jacobaea	tansy ragwort	Y	Y*	Y*
Senecio vulgaris	common ragwort	Y	Y	Y*

continued, next page

TABLE 1, Continued

Latin Name	Common Name	OR	WA	BC
Annual/Biennial Forbs, continued				
Silybum marianum	blessed milk thistle	Y	Y	Y
Soliva sessilis	carpet burweed	Y	N	Y*
Tragopogon dubius	yellow salsify	Y	Y	Y
Trifolium arvense	rabbit foot clover	Y	Y	Y
Trifolium dubium	small hop-clover	Y	Y	Y
Trifolium subterraneum	subterranean clover	Y	Y	Y
Vicia hirsuta	hairy vetch	Y	Y	Y
Vicia sativa	common vetch	Y	Y	Y
Vicia tetrasperma	lentil vetch	Y	Y	Y
Vicia villosa	winter vetch	Y	Y	Y
Perennial Forbs				
Anchusa officinalis	common bugloss	N	Y	Y
Centaurea diffusa	spotted knapweed	Y	Y*	Y
Centaurea melitensis	Maltese starthistle	Y*	Y	Y
Centaurea nigra	black knapweed	Y	Y	Y*
Centaurea ×moncktonii (C. pratensis)	meadow knapweed	Y*	Y*	Y
Centaurea stoebe (C. maculosa)	spotted knapweed	Y	Y*	Y*
Cichorium intybus	chicory	Y	Y	Y
Cirsium arvense **(R)**	Canada thistle	Y*	Y	Y
Cirsium vulgare	bull thistle	Y*	Y	Y
Echium vulgare	Blue weed	Y	Y*	Y
Euphorbia esula **(R)**	leafy spurge	Y	Y*	Y
Hieracium pilosella **(R)**	mouse-eared hawkweed	Y*	Y*	Y
Hypericum perforatum **(R)**	St. John's wort	Y	Y	Y
Hypochaeris radicata	hairy cat's ear,	Y	Y*	Y*
Leontodon taraxacoides	lesser hawkbit	Y	Y	Y
Lepidium campestre	field peppergrass	Y	Y	Y
Lepidium latifolium **(R)**	broad-leaved pepper-grass	Y	Y	Y
Linaria dalmatica **(R)** *(Linaria genistifolia* var. *dalmatica)*	dalmatian toadflax	N	Y*	Y
Lotus corniculatus **(R)**	bird's foot trefoil	Y	Y	Y
Lotus pedunculatus **(R)** *(L. uliginosus)*	greater bird's foot trefoil	Y	Y	Y
Mentha pulegium **(R)**	pennyroyal	Y*	Y	Y
Plantago lanceolata	English plantain	Y	Y	Y
Potentilla recta	sulphur cinquefoil	Y*	Y*	Y
Rumex acetosella **(R)**	sheep sorrel	Y*	Y	Y*
Tanacetum vulgare **(R)**	common tansy	Y	Y*	Y
Vicia cracca	bird vetch	Y	Y	Y
Woody Shrubs/Trees/Vines				
Buddleja davidii	butterfly bush	Y	Y	Y*
Cotoneaster franchettii	orange cotoneaster	Y	N	Y
Crataegus monogyna	one-seed hawthorn	Y*	Y	Y*
Cytisus scoparius	Scot's broom, squid sage	Y*	Y*	Y*
Daphne laureola	spurge laurel, laurel-leaved daphne	Y*	Y	Y*
Genista monspessulana	French broom	Y*	N	Y
Hedera helix	English ivy	Y*	Y	Y*
Hedera hibernica	Atlantic ivy	Y*	Y	Y*
Ilex aquifolium	English holly	Y*	Y	Y
Ligustrum vulgare	European privet	Y	Y	Y
Malus pumila (M. domestica)	apple	Y*	Y	Y
Prunus avium **(R)**	sweet cherry	Y*	Y	Y
Pyrus communis	pear	Y*	Y	Y
Rosa eglanteria **(R)**	sweetbriar rose	Y*	Y	Y
Rosa multiflora	multiflora rose	Y*	N	Y
Rubus armeniacus	Himalayan blackberry	Y*	Y*	Y*
Rubus laciniatus	evergreen blackberry	Y*	Y	Y
Ulex europaeus	gorse	Y	Y	Y*
Vinca major	periwinkle	Y*	Y	Y
Vinca minor	lesser periwinkle	Y	Y	Y

the prairie, savanna, and oak woodland ecosystems of western British Columbia, Washington, and Oregon. Of these, 13 groups of INS were selected for detailed discussion in this paper because we believe them to currently be significant threats to the prairie and oak habitats of the WPG; broom (*Cytisus* spp.), blackberry (*Rubus* spp.), and knapweed (*Polygonum* spp.) species have been grouped together due to their similar management methods. Many INS are omitted from detailed description, such as the ubiquitous colonial bentgrass (*Agrostis capillaris*), because they are already widespread and naturalized. Other species that are not covered here may be problematic for specific management goals. For example, numerous INS, such as tall fescue (*Schedenorus phoenix)* and velvetgrass *(Holcus lanatus*) are problematic for butterfly habitats (Schultz et al. 2011).

Invasive Non-native Species

The definition of INS is used to denote the pest plants that we discuss. They qualify as "weeds" because they are not native in the WPG ecoregion, often colonize disturbed habitats, and are undesirable because they displace native vegetation. With their ability to establish, naturalize, and expand their range into native plant communities, these plants are clearly invasive (Radosevich et al. 2007).

The first stage of a plant invasion is the introduction phase, when a seed or a fragment from a rhizomatous plant becomes established. Seeds can be transported by wind, water, birds, animals, humans, or vehicles. All of these mechanisms contribute to transporting INS in prairie and oak habitats. INS that produce edible fruits are commonly distributed by birds (Gosper et al. 2005), and the seeds of many other species are wind dispersed. Motor vehicles are very effective vectors, and have the ability to spread new invasive plants considerable distances. Vehicle infestation patterns often follow roads; for example, road density was correlated to INS abundance in southern Vancouver Island (Lilley and Vellend 2009). Seeds that have the ability to physically adhere are easily transported to new areas by both animals and humans. Foot traffic is also a common distributor of seed; hikers or field crews that work in infested areas may unwittingly transport undesirable vegetation. Mowing equipment, such as tractor mounted brush cutters, can also disperse significant amounts of seed or plant fragments. In order to reduce this risk, decontamination protocols should be used, especially when dealing with highly invasive species. Boot brushes can be installed at trailheads and used by field crews before and after working in sensitive habitat. Equipment should be cleaned with compressed air and sprayed down when moving from a contaminated area to a decontaminated area. The maxim, "an ounce of prevention is worth a pound of cure" is especially true since once an INS is established it may be impossible to eradicate. When prevention fails, early detection/rapid response (EDRR) is the second best management strategy (Westbrooks 2004, Mooney et al. 2005).

Once an INS has successfully survived introduction, the colonization phase begins. There is often lag time after introduction, when INS essentially progress from an individual scale of expansion into a population scale. Once the INS becomes self-perpetuating it can exhibit exponential population growth. Land managers are often dealing with INS during the colonization phase. At this point, INS are expanding their range while land managers are trying to contain and reduce that expansion. Naturalization is the final phase of invasion, where INS have established self-sustaining populations, are widespread, and have integrated into the local plant community (Radosevich et al. 2007). Once an INS becomes naturalized, it is typically exceptionally difficult and expensive to manage.

Management Strategies

Since natural areas managers have limited budgets to protect natural resources, it is imperative to approach INS management strategically. Adaptive management is the predominant strategy and involves the following steps (Bossard et al. 2000): (1) establish management goals and objectives; (2) determine which INS have the potential to prevent attaining those goals and objectives; (3) identify methods for managing those INS; (4) develop a management plan to move conditions toward management goals and objectives; (5) monitor and assess the effectiveness of management actions; and (6) reevaluate, modify, and start the cycle again. Prioritizing species is usually necessary and should be based on ecological threat and the feasibility of management success, focusing on taxa that pose a high threat and/or are most feasible to manage (Hiebert et al. 1993). For more detailed accounts of management strategies and invasive plant ecology, we recommend the following sources: Radosevich et al. (2007), Kaufman et al. (2007), Mooney et al. (2005), Buckley (2008), Holt (2004), Dewey et al. (2004), James et al (2010), and Booth et al. (2010).

Top priorities are usually focused on INS that are known to be significant habitat modifiers and threaten rare species. For example, some INS modify the native bunchgrass community to the point where butterfly species are significantly deterred from using native plants for nectar and larval resources (Severns 2008). Another rare species, the streaked horned lark (*Eremophila alpestris strigata*), selects habitat with short, sparse vegetation (Pearson et al. 2005). Since these and other rare species are of top conservation priority, so too is management of the INS that impact their habitat.

Succession is an important biological principle to consider whenever managing INS. Often it is assumed that eradication of an undesirable species is the most appropriate course of action by default. However, land managers should always consider what is likely to replace the INS if it is eliminated. In some cases, the opened area may be colonized by another INS that is far more difficult to manage (Evans et al. 2008). Seeding or planting of native prairie species is often a critical step to take following treatment of INS. Similarly, it is important to consider population dynamics. Most of the INS discussed here are capable of significant and rapid expansion. These types of aggressive species are often top priorities for land managers because inaction would result in greater short term impacts as well as higher costs for management in the future to address these impacts. Existing native species populations should always be considered; since most INS treatments are done to enhance native biota, managers should select techniques that have the least impact on them. This may be done with careful herbicide application or timing treatments to occur when native plant species have senesced for the year (Gonzales and Clements 2010).

Management of INS requires careful consideration of desired and expected outcomes. In some cases the best strategy may be inaction if available treatments would benefit INS or are not cost effective. If vigilance, perseverance, and appropriate management strategies are used, many INS can be sufficiently suppressed and in rare cases complete eradication may be possible. However, there are numerous species that will require many years of attention, and usually some level of perpetual management will be necessary.

In most cases, management efforts should prioritize sites that are not already inundated with INS. Having management plans in place prior to INS introduction greatly improves the ability of stewards to respond quickly and effectively. Regular surveys, inventories, and monitoring should be done to detect new introductions, assess the scale of infestations, and measure the success of management actions (Dewey et al. 2004). Prevention measures should be put in place whenever possible.

Most invasive plant species are best managed with integrated strategies that utilize several different methods. Recent research has shown that combinations of prescribed fire, herbicide application, and direct seeding can result in decreased infestations of target invasive plants and increased native plant abundance. A study replicated at 10 upland prairie sites in Oregon, Washington, and British Columbia, found a large reduction in invasive grasses resulting from combined treatments of grass specific herbicide followed by fire, then, after a two to three week period to allow for resprouting, application of a non-selective herbicide (Stanley et al. 2008, 2011b). In this study, mowing alone was generally a poor strategy for reducing herbaceous invasives and increasing native plants on prairies. The study also found that prairies across the ecoregion are strongly seed-limited: native diversity does not increase after treating INS unless seeds of desired species are added.

Mechanical Methods

Generally, mechanical methods refer to physical removal of plants by hand pulling, weed wrenches, mowers, weed whackers, chainsaws, or other machinery to cut or remove vegetation. Mechanical methods are often effective for controlling woody shrubs that do not possess rhizomes. Care must be taken when using mechanical methods to ensure that equipment does not transport seed to uninfested areas. For large infestations where resources do not allow targeted treatment of the entire infestation, managers may use mechanical techniques, such as tractor mowing, as a management strategy. Timing of such strategic mowing is often done to prevent seed production. As with the application of any method, consideration for the native plant and animal communities is paramount. For example, if annual mowing is necessary for an area with a high density of native plants it ideally would be done when the desirable vegetation has senesced (typically after early or mid-July for the WPG). Localized mechanical treatments can also be effective for annuals, if performed when populations are in flower or bud stage, by preventing the plants from going to seed. In the WPG, mowing tends to be most efficacious for shrubs but is also effective when used to stimulate green-up prior to herbicide application for invasive grasses.

Chemical Methods

A pesticide is a chemical or substance that is used for killing undesirable pest organisms; herbicides are a subset of pesticides that specifically target plants. Herbicides are often the most practical and efficient way of removing invasive plants from natural areas. There are two types of systemic herbicides in which plants metabolize the active chemical: selective and non-selective. Selective herbicides are effective against certain groups of plants, such as grasses or broadleaf species, whereas non-selective herbicides affect nearly all plant species. Pre-emergent herbicides differ from systemic herbicides in that they inhibit development of germinating seeds and are often used to suppress annual invasive plants and perennials with a short life cycle. Contact herbicides differ from systemic herbicides in that the chemical is not translocated by the plant, but rather kills the plant where it makes contact. Thus, contact herbicides behave similarly to fire, and if application is timed correctly, desirable vegetation may be unharmed. Aquatic herbicides may be used on or near aquatic systems because they are formulated to be of low toxicity to aquatic invertebrates and fish. Several herbicides that are commonly used in the ecoregion are shown in Table 2.

Herbicides should be carefully selected by natural area managers. Effectiveness is usually the leading consideration but must be balanced with environmental risks. Toxicity to applicators, wildlife, environmental persistence, mobility hazards, and bioaccumulation are all factors that contribute to the overall hazard of an herbicide. Thurston County's Integrated Pest Management program has a very good summary of risks for commonly used terrestrial and aquatic herbicides (Thurston County 2011). Generally, the least toxic but effective herbicide should be selected. Adjuvants are often mixed with herbicides to enhance their effectiveness. An adjuvant may be formulated with surfactants (often referred to as wetting agents or spreaders), penetrants, stickers, water conditioners, anti-drift agents, and/or defoaming agents. Adjuvants are not herbicides and toxicity information for them is not always readily available. Although they are generally assumed to be less toxic than most herbicides, they can sometimes be more toxic. For example, glyphosate is the active herbicide ingredient for both Aquamaster and Round-up, but Aquamaster is aquatic-approved while Round-up is not due to the adjuvants used in the formula to increase efficacy. There is a wide selection of adjuvants available which can make selection difficult. Additionally, some adjuvants are aquatic-approved and may be used in conjunction with aquatic herbicides. It is always important to read the herbicide label to determine which type(s) of adjuvants are recommended. Adjuvants most often used in the WPG ecoregion include Nufilm IR, Hasten, Liberate, LI-700, MSO concentrate, and R11.

Biological Methods

Biological control (biocontrol) employs biological agents to suppress INS populations. Biological agents are often non-native insects (native to the same geographic area as the target plant) that consume the target plant or its seed, but can also be a fungus or other organisms that stress the plant through predation, defoliation, or parasitism. To reduce potential for damage to non-target species, biological agents go through an extensive certification process before they are available (Turner 2007). Biological agents can be in high demand and difficult to acquire. It may take time for an agent to reach a population level that can make a significant impact on the target species. In general, few resources have been available for the development of biological agents in prairie and oak

TABLE 2. Herbicides in use to treat invasive non-native plant species in the WPG ecoregion.

Herbicide Selectivity	Chemical Name	Trade Name	Type
Grass-specific	Sethoxydim	Poast	Systemic
	Fluazifop	Fusilade DX	Systemic
	Clethodim	Envoy	Systemic
Broadleaf-specific	Aminopyralid	Milestone VM	Systemic
	Triclopyr amine	Garlon 3A	Systemic
	Triclopyr ester	Garlon 4	Systemic
	Clopyralid	Transline	Systemic
	2,4-Dichlorophenoxyacetic acid	2,4-D	Systemic
Non-selective, terrestrial	Glyphosate	Round-up/Accord	Systemic
	Nonanoic acid	Scythe	Contact
	Hexazinone	Velpar	Contact
	Oryzalin	Surflan	Pre-emergent
	Pendimethalin	Pendulum	Pre-emergent
Non-selective, aquatic	Glyphosate	Aquamaster	Systemic
	Imazapyr	Habitat	Systemic

ecosystems. For example, certain fungal pathogens and insects show some promise against Scot's broom (*Cytisus scoparius*) but little has been done to develop this potential (Peterson and Prasad 1998). Other examples of biological methods are discussed later with reference to particular invasive plants.

Prescribed Fire

Fire is an effective means of reducing the abundance of certain invasive plants, particularly woody shrub species. Some herbaceous INS are fire-adapted and respond favorably to fire, while others decline in abundance with prescribed fire (Hamman et al. 2011, Nuckols et al. 2011). Fire is also used to reduce fuel loads, deplete weed seed banks, and to stimulate germination, growth, and spread of native vegetation. If INS emerge following a fire before the native vegetation, then herbicide may be used without impacting natives.

Other Methods

Other potential tools for managing INS include manipulating water levels or nutrient availability, covering with opaque landscape fabric, or solarization with clear plastic, and grazing by livestock. Physical methods can be used to limit or increase the amount of water, humidity, temperature, and nutrients. Covering an invasive plant with landscape fabric for at least one growing season will block access to sunlight, and can suppress plants very effectively; using a clear plastic over moist, tilled soil traps heat from sunlight during the summer and effectively cooks plants and seeds underneath (Rubin and Benjamin 1984; Eric Delvin, University of Washington Graduate Student, personal communication). For example, tilling followed by 1 year of solarization with clear plastic completely eliminated patches of reed canary grass (*Phalaris arundinacea)* in a wet prairie site in the Willamette Valley (Wilson and Ingersoll 1993). The use of grazing animals such as goats or cattle to consume invasive plants is becoming more popular. However, this method is often non-selective and therefore may require careful timing or may not be desirable in areas where native plant communities are present.

Invasive Plant Species of the WPG

The following species descriptions document some of the particularly problematic invasive plants that occur on natural areas in the ecoregion, including the most effective management methods, related research or trials, and future outlook. We categorize plants into general functional groups: shrubs, grasses, forbs. We do not give a comprehensive distribution of INS in the WPG, but do indicate occurrence by state/province, and which are specific management targets (Table 1).

Invasive Shrubs

Scot's Broom (*Cytisus scoparius*), French Broom (*Genista monspessulana* or *Cytisus monspessulanus*) and European Gorse (*Ulex europaeus*)—*C. scoparius*, *U. europaeus,* and *G. monspessulana* are discussed here jointly due to their similar life history and treatment methods. All three of these shrubs are from the pea family (Fabaceae) and have green stems and showy yellow flowers. Seeds lack specialized long distance dispersal adaptations but the fruits dehisce explosively, propelling the seeds a short distance. Brooms and gorse all can dominate open grassland habitats if not managed. *C. scoparius* is very problematic in British Columbia (Peterson and Prasad 1998) and south Puget Sound. It is also common in many areas of the Willamette Valley, where it is joined in the southern part of the valley by *G. monspessulana*, a common invasive shrub in California. *C. scoparius* may spread into oak-grassland habitats from nearby disturbed areas (e.g., roadsides), or may take advantage of disturbance caused by removal of other invasive species (MacDougall et al. 2008). *U. europaeus* presents similar challenges, although it is less widespread at present in the WPG ecoregion (Clements et al. 2001). The distribution of *U. europaeus* on southern Vancouver Island and the Gulf Islands in British Columbia closely parallels the distribution of the Garry oak ecosystem itself, although *U. europaeus* does not tend to form populations in British Columbia as frequently or as large as in more southern areas such as Oregon, where *U. europaeus* is primarily coastal (Clements et al. 2001).

These shrubs can be several meters high, and tend to form thick patches that shade native plants and compete for nutrients. Although they are nitrogen-fixers, the input of nitrogen into the soil is relatively minor, and their impact on nutrient dynamics is primarily to remove phosphorus available to other species, according to recent research on *C. scoparius* in British Columbia (Shaben and Myers 2010). Additionally, allelopathic properties have been demonstrated that may inhibit native plants grown in soils invaded by *C. scoparius* (Haubensak and Parker 2004, Dougherty and Reichard 2004). Recent studies by Rook et al. (2011) in a south Puget Sound prairie suggest that soil legacy effects from broom infestations may affect subsequent native species plantings. Prolific seed production and long-lived seed from all three species lead to rapid spread and formation of seed banks that can persist for several decades.

Several trials have been conducted on various control methods for *C. scoparius* (Peterson and Prasad 1998, Ussery and Krannitz 1998, Dougherty and Reichard 2004, Delvin et al. 2005). The Garry Oak Ecosystem Recovery Team (GOERT) has produced an extensive list of best management practices for controlling *C. scoparius* (GOERT 2002), and The Nature Conservancy of Washington has reported techniques and strategies for integrated control (Dunn 2002).

Mechanical Methods—Hand pulling can be effective for controlling *C. scoparius* and *G. monspessulana* if the entire tap root is removed. This is practical for small infestations and young plants. Mature plants have thick, tough stems that are difficult to completely remove, even with a weed wrench. Removing the root system of large plants can cause considerable soil disturbance, which can hinder recovery of the native herbaceous vegetation. Mowing results in some mortality, but more importantly it keeps the plant from setting seed, lessens fire intensity by reducing shrub stature, and makes herbicide application easier since mature broom is too tall for backpack and boom sprayers. Cutting stems at ground level can result in significant mortality, especially to large plants. Bossard and Rejmanek (1994) found that cutting *Cytisus* stems during the dry season (late summer and early autumn) reduced the re-sprout rate to less than 7%. This method must be repeated every few years, before regenerating or resprouting plants reach flowering size, in order to prevent seed production. Painting cut stumps with herbicide is useful to prevent re-growth (Becker, Clements and Kunstar, unpublished data), although simply burying cut stems with soil may also help suppress regrowth. Mulching has been shown to significantly decrease seedling emergence of *G. monspessulana,* indicating that mulching could be used to suppress regrowth after removal of mature plants (Bossard et al. 2000).

Using mechanical methods to treat *U. europaeus* are often challenging. It is possible to remove seedlings and young plants (to 1.5 m tall) with weed wrenches (GOERT 2009). Mechanical methods of removal that have been used include mowing, chaining (dragging a heavy chain between two bulldozers), root raking, and cultivation (Hoshovsky 1986, King et al. 1996). However, the sharp spines are problematic, and repeated mowing can create large areas covered by low, monospecific stands that spread by vegetative means similar to runners; the mowed plant's branches spread laterally and are able to produce roots where branches contact the ground, thus extending the patch outward. Plans are underway to experiment with techniques such as fire or chemical control to attempt to break the stalemate created by annual mowing (James Miskelly, Department of National Defence, personal communication). Cultivation, if repeated annually for 3 or 4 years, may gradually deplete a gorse seed bank (Boyd 1985).

Chemical Methods—Several herbicides are effective on *C. scoparius* and *G. monspessulana*. Various chemical agents, such as triclopyr, picloram, hexazinone or fluroxypyr have resulted in 80 to 90% mortality for *C. scoparius* (Peterson and Prasad 1998). Triclopyr ester is the herbicide of choice for both broom species, although aminopyralid is also very effective, as is the combination of the two, particularly for fall application. For mature plants, the preferred practice is a combination of cutting and spraying. In British Columbia, mechanical treatment is generally preferred over chemical treatment. For younger plants or smaller infestations, spot-spraying of whole plants is effective. The timing for herbicide treatment is crucial because desirable non-target species may reside below the target shrubs. To avoid these desirable plants, herbicide is foliar-applied in late summer and early fall when the majority of native plants have senesced.

For *U. europaeus*, a variety of herbicides have been shown to be effective against either young plants or freshly cut stumps (King et al. 1996, Clements et al. 2001). Glyphosate has been shown to be more effective in combination with surfactants or other herbicides.

Grazing—On sites with high populations of ungulates, *C. scoparius* growth may be curtailed by grazing. Grazers such as black-tailed deer are unlikely to kill individual plants, but rather tend to reduce reproductive capacity through pruning of branches, which leads to reduced flowering and seed set (Shriner and Clements, unpublished data). Some attempts have also been made to utilize sheep and goats to control *C. scoparius*. Effective control of *U. europaeus* and *G. monspessulana* by goats has been demonstrated in New Zealand (Radcliffe 1985). However, a sufficiently intense grazing pressure to kill broom or gorse would likely also result in negative impacts to the remnant native prairie community as well.

Biological Methods—Biological agents for *C. scoparius* have been introduced to the western U.S, including a twig-mining moth (*Leucoptera spartifoliella*) and the seed weevil (*Apion fuscirostre*). Success is apparently limited in the cooler climatic conditions of British Columbia (Peterson and Prasad 1998), but more research is needed to determine the extent to which biological control agents introduced to the U.S. have colonized British Columbia. The gorse seed weevil (*Apion ulicis*) shows some potential to limit reproduction of *U. europaeus* (Clements et al. 2001, GOERT 2009). Trials have also been done with fungal pathogens, where *Chondrostereum purpureum* shows good potential for control of *U. europaeus* if it can be developed commercially as a mycoherbicide (Prasad 1996). There are no biocontrol agents available for *G. monspessulana* (Bossard et al. 2000).

Fire—If it is an option for land managers, fire is the tool of choice for managing *C. scoparius*. As with other methods that remove the top of the plant, *C. scoparius* and *G. monspessulana* may regrow from their roots following a fire (Bossard et al. 2000, Boersma et al. 2006). However, most fires are sufficiently hot to destroy the cambium, killing most *C. scoparius* plants and stimulating the seed bank. This is the preferred method for *C. scoparius* on south Puget Sound grasslands. With several cycles of prescribed fire, these shrubs and their seed banks have been drastically reduced. Dense stands of *C. scoparius* may increase fire intensity and increase mortality of native prairie grasses and forbs. This potential deleterious effect can be mitigated by mowing prior to a burn.

Observations and Outlook—C. scoparius is likely to be a permanent resident of the Pacific Northwest. Its widespread distribution and high levels of reproduction and persistence make it one of the greatest threats to grassland habitats in the WPG. Proper management, particularly with fire, can keep natural areas relatively free of this plant. Manual mechanical treatment has also been successful in some south Puget Sound prairies where large numbers of volunteers have been deployed repeatedly for many years. Perpetual management efforts will be required to keep this plant in check. In general, the best management practices recommended for management of *C. scoparius* (GOERT 2009) also apply to *G. monspessulana* and *U. europaeus*. Because distribution of *G. monspessulana* is currently relatively sparse, early detection and rapid response strategies are all the more important.

Laurel-leaved Daphne (*Daphne laureola*)—*D. laureola* is a shrubby plant (up to 1.8 m) in the Thymelaeaceae family with dark, glabrous evergreen leaves with prominent mid-veins at the tip of its stems (GOERT 2009). It produces yellowish-green flowers in terminal clusters, and small purple fruits that are dispersed by birds.

Although less likely to invade oak savannas, *D. laureola* has the potential to be very detrimental in oak woodland or forest habitats, where it can rapidly form monotypic stands. Such an invasion can result in depletion of native flora and altered soil chemistry (Prasad 2005, GOERT 2009). The potential toxicity to humans of the leaves, bark and fruits of *D. laureola* complicates eradication efforts (Burrows and Tyrl 2001).

Mechanical Methods—Smaller plants and infestations are relatively easy to remove by hand pulling or using a weed wrench (especially if the soil is moist), with care taken to remove as much root as possible to prevent resprouting (GOERT 2009). GOERT (2009) recommends using loppers to remove larger plants at the soil level. To avoid the toxic sap, gloves should be worn for these operations. Care must also be taken to avoid soil disturbance, which could promote seed germination (Webb 2006). The removal of the top portion of young plants up to three years old appears to result in very high mortality (>95%), so the use of a weed whip may be more efficient at killing large patches of seedlings. Protective gear should be worn because volatile plant toxins will be released (Webb 2006).

Chemical Methods—Applications of glyphosate to cut stems has been recommended to prevent resprouting (Boersma et al. 2006); triclopyr has likewise been found to be effective (Prasad 2005).

Biological Methods—Some noctuid moth larvae (e.g., *Trigonophora flammea* and *Noctua janthe*) have been investigated as potential biological control agents for *D. laureola*, but these may not be specific enough, and it has not been considered a high enough priority for the introduction of such agents (Boersma et al. 2006, Kimber 2006). Preliminary studies of the fungus *Phomopsis* showed it to be very effective against *D. laureola* under field, greenhouse, and growth chamber conditions, but unfortunately there is no ongoing research on this potential (Byrne 2004, Prasad 2005).

Fire—Fire effects on *Daphne* are unknown.

Observations and Outlook —D. laureola is an emerging problem in the Georgia Basin within oak habitats of concern, as well as in forestry and riparian habitats. It is present at low abundance in scattered localities in the Willamette Valley, and was detected for the first time on prairies (under a small oak stand) on Joint Base Lewis-McChord in 2010. Because relatively little is known of its biology and management, greater efforts are needed to reduce nascent populations before it is too late to curtail potentially widespread distribution.

Blackberries (*Rubus armeniacus, R. laciniatus, R. vestitus, R. macrophyllus)*—Himalayan blackberry, *Rubus armeniacus (syn. with R. discolor, R. procerus),* is a prominent invasive shrub found in a variety of habitats in the Pacific Northwest. Armed with hooked prickles, *R. armeniacus* has large, rounded evergreen leaves, forms extensive thickets via evergreen growth, and produces white or pinkish-white flowers and numerous purple or black fruits. The fruits are eaten by wildlife and are thus readily dispersed. The evergreen blackberry (*R. laciniatus*) is also an invasive species growing in similar habitats but less frequently, and is distinguished by "cut leaves" with five leaflets. A related species, *R. vestitus*, is becoming common in parts of the Willamette Valley, where it typically occurs in more mesic or shady habitats. It is distinguished by stipitate-glandular inflorescences and more strongly pinkish flowers. *R. macrophyllus* is another member of this complex that has been collected in western Washington. All of these taxa of introduced blackberry are invasive in natural areas, and treatment strategies need not be separated for individual taxa.

R. armeniacus forms much denser thickets than *Rubus* species native to western North America. Its growth can result in conversion of prairies into shrub-dominated ecosystems, and even prevent establishment of trees (GOERT 2009). *R. armeniacus* frequently invades prairie, savanna, and oak woodland habitats throughout the WPG. Although *R. armeniacus* thickets can provide cover for animals, including non-native animals like the black rat (*Rattus rattus*), evidence suggests that nesting by native birds is reduced in areas where *R. armeniacus* is the dominant vegetation (Astley 2010).

Mechanical Methods—Although seedlings and young plants are relatively easy to remove with handpulling, larger plants are best managed with machetes or brush cutters. The plants will usually resprout if the roots are not removed. The plant resprouts most vigorously from the woody burl at its base following mechanical treatment, but new stems can resprout from any piece of root left in the ground, making it is very difficult to completely eliminate *R. armeniacus* from a given patch of habitat by mechanical or manual methods. Mowing is a cost-effective treatment for reducing the biomass and cover of existing large infestations, and allows for the release of native forbs that have survived in a somewhat suppressed state but are not subject to competition from non-native grasses. Especially if combined with prescribed fire on a regular rotation, mechanical treatments provide a reasonable set of tools to keep Himalayan blackberry in a reduced state that will allow native prairie vegetation to persist. Experiments in the Willamette Valley show that mowing annually in the fall keeps blackberry from expanding, and mowing twice per year (February and September) reduces its abundance by over 70% after three years of repeated application (Thorpe et al. 2008). It is recommended that for large patches, new growth be cut in July or August to prevent the growing tips from re-rooting and extending the size of the patch (GOERT 2009), but mowing outside of the growing season may be effective and help avoid damage to native vegetation, including rare plants and butterflies (Thorpe et al. 2008).

Biological Methods—*R. armeniacus* has few known natural herbivores in North America, partly due to heavily armored stems that prevent browsing (Caplan and Yeakley 2006). In Eurasia, *R. armeniacus* is parasitized by a fungal rust (*Phragmidium violaceum*) that has only just been discovered in Oregon (Bennett 2007), but there is no evidence that *P. violaceum* has spread north. Preliminary evidence from Oregon suggests that while the rust does not cause direct mortality, it does significantly reduce the vigor of *R. armeniacus* (Bennett 2007).

Chemical Methods—*R. armeniacus* can be effectively treated with glyphosate or triclopyr herbicides. Late summer or early autumn is the most effective season for treatment, especially after resprouting following a fire. Native forbs are mostly dormant by this time of the year so the risk of collateral damage to desirable vegetation is lowered if a broadleaf specific herbicide is used.

Fire—Controlled burning substantially reduces blackberry. In a Willamette Valley experiment (Thorpe et al. 2008), burning reduced blackberry cover by nearly 70%, and cover remained reduced for two years. Ideally, patches of *R. armeniacus* should be mowed before prescribed fire is applied, because many years of accumulated dead blackberry canes can lead to high fire severity that could harm surviving populations of native prairie plants.

Observations and Outlook—*R. armeniacus* is well established throughout the WPG and is unlikely to be completely eliminated from prairie and oak habitats. However, its ecological impact in conservation areas can be significantly reduced through a combination of mechanical and chemical treatments, as well as prescribed fire where this is feasible.

Invasive Grasses

Invasive non-native grasses are one of the greatest threats to the structure and function of grassland systems in the WPG. Grasses have the potential to form dense monocultures, effectively suppressing native vegetation and the fauna it supports. Here we present information on several invasive grass species that have emerged as the most urgent threats in the WPG. There are many other non-native annual and perennial grasses present in these natural areas (Table 1), which may be managed with similar techniques as outlined for the species below.

Tall oatgrass (*Arrhenatherum elatius*)—*A. elatius* is a perennial bunchgrass with both bulbous (var. *bulbosum*) and non-bulbous varieties. Native to Europe, it may grow to 2 m tall (Hitchcock and Cronquist 1973) and can transform grassland structure and composition and increase fire intensities. Shifts in structure and species diversity caused by *A. elatius* can make habitat unsuitable for rare and desirable plants and Lepidoptera (Severns 2008). Due to the threat that *A. elatius* poses for rare species as well as the overall habitat, considerable attention has been focused on treating and excluding this grass from prairies in south Puget Sound and the Willamette Valley. It is found primarily in upland prairies and savannas and does not appear to be problematic in hydric soils of wet prairies. The bulbous variety occurs somewhat less frequently than var. *elatius* in the WPG ecoregion, but still occurs throughout much of the range of the species, and could be encountered in any upland prairie or savanna site under management.

Mechanical Methods—Mechanical methods are an important adjunct to herbicide treatments, and produce some beneficial results alone where fire and herbicides are restricted. Mowing in the spring, at heights that avoid native flora, can hinder *A. elatius* by reducing the amount of energy reserves in the plants, and when repeated annually can substantially decrease abundance. This method converted an invaded prairie to one dominated by native grasses after four years of treatment (Wilson and Clark 2001). Another study that compared integrated management techniques demonstrated that mowing alone moderately reduced *A. elatius* abundance, whereas combination treatments with herbicide, and herbicide with fire, produced large declines in abundance (Stanley et al. 2011a). While these studies demonstrate that mowing can have an impact on *A. elatius*, it is not likely to eradicate it and progress can be quickly reversed if mowing were to cease.

Chemical Methods—Herbicide is the primary means for managing *A. elatius*. The current preferred strategy is to spray in the April-May window prior to the plant bolting, or when it is 8 to 12 inches in height, with fluazifop butyl or sethoxydim. The very wet springs that frequently are typical of the Pacific Northwest may make spring applications logistically challenging, which is one reason why mowing combined with spraying is sometimes necessary prior to the plant setting seed in early summer.

Several trials have been implemented to determine the most effective herbicide and surfactant for controlling *A. elatius*. In 2007 fluazifop and sethoxydim treatments on *A. elatius* were compared in south Puget Sound. Using 1x1 meter plots, fluazifop, sethoxydim, and controls were established; the herbicide plots were treated the last week of April with solutions of 0.75% fluazifop + 0.25% Nufilm IR, and 1.5% sethoxydim + 0.5% Agridex. After treatment fluazifop reduced cover by 51% ($p=0.0011$) while sethoxydim reduced cover by 23% ($p=0.0262$) (The Nature Conservancy, 2008). A trial implemented at Mima Mounds Natural Area Preserve compared the surfactants NuFilm IR (0.25%), MSO (methylated seed oil) (0.78%), and Liberate (0.58%) when used with fluazifop (0.78%). Results one year after treatment demonstrated a 58% reduction using NuFilm IR, a 39% reduction using MSO, and a 3% reduction using Liberate (Wilderman and Davenport 2009).

In a regional study of prairie restoration, treatments that included burning and/or mowing in combination with herbicides provided the most consistent and effective control of *A. elatius* (Stanley et al. 2011a). For example, application of sethoxydim, followed by fire, with subsequent spray of glyphosate two to three weeks after the burn, substantially reduced the species at three sites in Washington and Oregon. Sethoxydim followed by mowing also provided excellent control of *A. elatius*, as did mowing followed by burning and glyphosate application. Mowing alone in the spring and fall also reduced this grass but to a lesser degree than treatment combinations that included herbicide.

Fire—*A. elatius* is not a fire-adapted species but is not controlled by fire. Anecdotal observations indicate that fire may limit expansion, but it has little to no effect at reducing infestations. Since managers aim for fire frequencies no shorter than 3 years, fire alone is not a viable means for managing *A. elatius*. However, if glyphosate is applied two to three weeks after a burn when *A. elatius* begins to resprout, very effective control can result, with the dual advantage of fewer non-target impacts and less herbicide use (Stanley et al. 2011a).

Observations and Outlook—*A. elatius* will almost certainly continue to require considerable attention from land managers in prairies throughout the WPG.

Its rapid establishment and population growth, ability to modify the vegetative and structural characteristics of grassland habitat, and propensity to deter at-risk species (such as rare herbaceous plants and Lepidoptera) in particular makes effective management of this plant a top priority. Additional research is also needed to determine whether mowing and herbicide treatments are as effective on var. *bulbosum* as they are on var. *elatius*.

Sweet Vernal Grass (*Anthoxanthum odoratum*)—*A. odoratum* is a 30 to 60 cm tall tufted perennial with hollow, hairless stems and a 2 to 9 cm brownish-yellow panicle (GOERT 2009). Its common name refers to its sweet vanilla odor and relatively early flowering. The plant produces coumarin, which is thought to have potential allelopathic impacts on other plant species (Yamamoto 1995).

Native to Eurasia, *A. odoratum* was introduced to North America as a pasture grass in the 1700s and is now found in eastern North America and from northern California to Alaska on the west coast. It is widely distributed through Garry oak ecosystems in British Columbia, and is particularly common in open prairies where it often comprises more than 30% of the vegetation cover (GOERT 2009). It can also occur in high abundance in wet prairies in the Willamette Valley. Its impact on grassland habitats in the WPG includes outcompeting native vegetation for light, water, and nutrients, and producing a thick litter layer. The high-nitrogen litter can impact native vegetation unaccustomed to high levels of nitrogen, and phosphorus produced by its decaying roots may enhance growth of other grasses that further impact native forbs (GOERT 2009).

Mechanical Methods—Hand pulling or hoeing can effectively control small patches of *A. odoratum*, but such measures are impractical for larger infestations (GOERT 2009). Repeated mowing of *A. odoratum* in early spring and late summer shows some promise for favoring successional trajectories leading to higher proportions of native forbs. A five-year trial on Salt Spring Island, BC, utilizing 1x1 m plots found that a combination of mowing to control the *A. odoratum* and fencing to keep out ungulates (black-tailed deer and feral sheep) was most successful in reducing populations of *A. odoratum* and increasing populations of native forbs (Gonzales and Clements 2010). The mowing treatments also included discarding the litter that resulted from mowing, which was largely comprised of *A. odoratum*.

Chemical Methods—Grass-specific herbicides effectively kill established *A. odoratum*. Many other native grasses are susceptible as well, but some key native prairie species, such as Roemer's fescue (*Festuca roemeri*) and graminoids like sedges (e.g., *Carex* spp.) and rushes (e.g., *Luzula*, *Juncus* spp.) are immune to grass-specific herbicides when applied at standard rates However, in wet prairies where *A. odoratum* is a problem in the Willamette Valley, grass-specific herbicides may negatively impact abundant native grasses (e.g., *Danthonia californica, Deschampsia cespitosa).*

Biological Methods—In areas with abundant herbivores, the presence of grazers tends to enhance *A. odoratum* because ungulates such as deer or sheep prefer to graze on native species rather than *A. odoratum* (Gonzales and Arcese 2008, Gonzales and Clements 2010).

Fire—*A. odoratum* often increases in abundance after fire, so prescribed burning should be used with caution when this species is present. Experimental mowing and burning in Oregon wetlands resulted in increases in *A. odoratum* when compared to controls (Clark and Wilson 2001). In this study, both treatments were applied twice, two years apart. In another study in upland prairies, *A. odoratum* increased or was unaffected in burn treatments compared to controls, especially at a Georgia Basin site where the species was abundant (Stanley et al. 2011a). However, treatment combinations that included sethoxydim in combination with burning or mowing substantially reduced *A. odoratum*.

Observations and Outlook—The widespread and pervasive presence of *A. odoratum* in some areas of the WPG is a major management challenge. If sufficient resources can be obtained to apply the successful combinations of treatments such as are described above to large areas, the affected ecosystems could be restored to include a larger native forb component. In the Georgia Basin it appears that herbivory drives the system more than competition (Gonzales and Arcese 2008), and it is clear that, as in many cases involving invasive species, land use changes may contribute to the dominance of perennial grasses like *A. odoratum* and *Dactylis glomerata* (MacDougall and Turkington 2005).

Orchardgrass (*Dactylis glomerata*)—*D. glomerata* is a tall perennial bunchgrass up to 1.5 m in height with a tufted panicle ranging from 3 to 15 cm in length. *D. glomerata* was introduced to North America as a pasture grass and to stabilize soil. It now is widespread, and does well in Garry oak systems in British Columbia, particularly where there is ample light and nitrogen (e.g., where nitrogen levels are increased by the presence of other invasive plant species, or from historical land uses). In many prairies and savannas it has become the dominant grass species, and is considered one of the worst invasive grasses in British Columbia Garry oak systems (Boersma et al. 2006). Like many other non-native perennial grasses, *D. glomerata* competes for nutrients, light, and water, and produces litter that alters the physical environment and soil chemistry.

Mechanical Methods—Hand pulling or hoeing can be effective for small patches in early summer prior to seed set; it is important to try to remove the frequently extensive root system of *D. glomerata*. Use of a flame torch on remaining roots in the fall may help prevent resprouting (GOERT 2009). For larger infestations, larger-scale treatments such as intensive mowing regimes are necessary to shift the balance away from these perennial grasses (MacDougall and Turkington 2007). However, mowing should be timed to coincide with early summer growth as specified above; repeated mowing may actually stimulate growth in some cases (Boersma et al. 2006). One study suggested that mowing twice a year resulted in moderate to no decline, but mowing once in combination with herbicide treatment, or herbicide and fire, resulted in large declines (Stanley et al. 2011a).

Chemical Methods—Many grass herbicides are effective against *D. glomerata*. However, they are not specific to this species and care must be taken to avoid collateral damage to native grasses (Boersma et al. 2006). On the other hand, invasive grasses like *Holcus lanatus* and *Poa pratensis* are also sensitive to grass specific herbicides, so treatment efforts to control one invasive grass may have similar impacts on others (Stanley et al. 2011a).

Fire—The effect of fire on *D. glomerata* is not clear. Some literature claims that it is sensitive to fire, and thus restoration treatments involving fire can be effective (MacDougall and Turkington 2007); others demonstrate that in certain locales it may persist and even increase after a summer burn (Dunwiddie 2002, Boersma et al. 2006).

A number of trials have already been completed in sites where the dominant invasive grasses are *D. glomerata* and *Poa pratensis*, and additional trials are underway. One of the most extensive trials to date was a 5-year evaluation of three restoration techniques: fire, cutting and raking, and weeding (MacDougall and Turkington 2007). The trials found significant differences among treatments, indicating that the beneficial effects of reducing biomass of invasive grasses by fire can be duplicated by other restoration treatments. They still suggest fire has advantages over other treatments in these fire-adapted landscapes, but that in systems where risks of using fire are deemed too great, other methods to remove invasive grasses may be attempted. At the same preserve, Stanley et al. (2011a) found that treatments including sethoxydim reduced *D. glomerata* to near zero cover, down from an average cover of about 10% in control plots. Mowing, combined with burning, and followed by glyphosate application after a two to three week delay, also substantially reduced its abundance, but to a lesser degree.

Observations and Outlook—Although the results of experimental treatments show that *D. glomerata* populations can be reduced, the widespread infestation of British Columbia's oak and prairie habitats by this species represents a seemingly insurmountable challenge. However, other efforts are also underway, most notably by Parks Canada in the Gulf Islands National Park Reserve, where some efforts are being made to introduce prescribed burning that would likely help curb populations of *D. glomerata* and other introduced grasses. As demonstrated by the work of Stanley et al. (2011a), carefully designed combination treatments are the best strategy for successful reduction of *D. glomerata*.

Slender False-brome (*Brachypodium sylvaticum*)—*B. sylvaticum* is rapidly invading forests, oak savanna, and prairies in the Pacific Northwest (Kaye and Blakeley-Smith 2006). It is distinguished from many other grasses by its hairy leaf margins and lower stems; broad, drooping leaves; nodding flower spikes; and long-lasting bright green color that often persist through fall and at least part of winter. The species is abundant in western Oregon from sea level to elevations over 1,000 m. Infestations reported from Washington have so far been small and rapidly extirpated after detection, although there are likely undetected occurrences. *B. sylvaticum* has also been found in British Columbia. This perennial can dominate the ground cover in a wide range of habitats, from shady environments such as a forest floor, to sunny sites like pastures and prairies. Such a broad tolerance to varying light levels makes *B. sylvaticum* unusual among WPG invasive plants. The plants reproduce by seed only, and seeds live about two years in the soil (Fitzpatrick and Kaye, unpublished data).

Mechanical Methods—Mowing alone does little to reduce *B. sylvaticum*, but it can be used to limit the spread of the species by reducing or eliminating seed production in a given year, if conducted prior to seed maturation in June. Mowing followed by mulching with straw or wood chips effectively reduces abundance and suppresses seed production for a second year. Hand pulling that removes the roots is effective for small infestations, but should be followed up for one or two years to catch resprouts and seedlings.

Experiments to develop mechanical methods for *B. sylvaticum* have focused on mowing, tilling, and mulching. Plots (2 x 2 m) treated in Oregon in fall 2002 showed that mulching was the most effective method for reducing frequency and cover through 2004. The native blue wildrye (*Elymus glaucus*) seeded into the plots established well, and may have helped suppress *B. sylvaticum*. Mulching, however, is only an appropriate treatment for small patches. A second experiment in 2007 using plots (1.5x2 m) at different sites in Oregon found that mowing in June eliminated seed production in that year, while mowing in May was ineffective (Blakeley-Smith and Kaye 2008). After one year, production of flowering tillers rebounded to 230 m^{-2} in plots that were only mowed, but adding mulch kept tillers to less than 20 m^{-2} on average.

Chemical Methods—Both non-selective (glyphosate alone or in combination with hexazinone (Velpar)) and grass-specific herbicides (fluazifop) can reduce *B. sylvaticum* by over 90% one year after a single application. Spring application of glyphosate is the preferred chemical approach, but in areas with substantial native vegetation this method may damage desirable vegetation. In such cases, spring application of grass-specific herbicide can minimize most non-target impacts. Also, because this grass remains green through late summer and fall, application of glyphosate after most native species have gone dormant (August and later) effectively reduces false-brome without killing the majority of natives. Follow-up applications may be necessary for two or more years to fully eradicate an infestation.

Chemical trials in late summer and fall 2002 and 2003 screened several products for their ability to reduce *B. sylvaticum*, including glyphosate, fluazifop, pendimethalin (Pendulum), and oryzalin (Surflan), alone or in combination (Clark et al. 2004). Applications that included glyphosate at 2.24 kg a.i. ha^{-1} reduced *B. sylvaticum* by 75% to 93% on average, while those that included fluazifop at 0.211- 0.42 kg a.i. ha^{-1} varied in control rate from about 20% to 76%.

Fire—False-brome resprouts vigorously after fire. Burning followed by spot spraying with herbicide is an attractive option where fire is possible, and can substantially reduce the amount of herbicide needed to eradicate an infestation.

Other Methods—Superheated foam generated from a Waipuna machine has been shown to reduce *B. sylvaticum* by up to 90%. This method involves spreading foam from hoses fed by a truck-mounted heating unit and water tank, and is useful for roadsides and other areas accessible by 60 m hoses. The equipment and application is relatively expensive and time consuming, but is useful in some areas. Tests with superheated foam from a Waipuna machine on experimental plots (1.5 m x 1.5 m) reduced false brome to less than 8% cover compared to 67% cover in controls one year after application, and killed nearly all seeds on the soil surface if they were moistened 24 hours prior to treatment (to simulate a fall rain).

Observations and Outlook—Since the original discovery of a false brome population in Oregon in 1969, the species has spread to tens of thousands of acres in the state. Initiation of the False Brome Working Group in 2001 has helped increase awareness and research on this species. Extensive surveys to document the distribution of the species in Oregon followed by aggressive outreach and targeted research to develop treatment methods has improved the outlook for containing its spread. Even so, new populations have been discovered in California and New York in the last few years, and some of these are large and well established. The species appears to spread most rapidly in wooded habitats, and moves into prairies and oak savannas from forest edges. It often starts in grasslands under isolated trees.

Invasive Forbs

Shining Geranium (*Geranium lucidum*)—*G. lucidum* is an annual forb in the Geranium family. It resembles several other introduced annual geraniums, such as *G. molle* and *G. dissectum*, which are present in natural habitats in the Pacific Northwest, but are generally less invasive in wildland habitats. *G. lucidum* has reniform leaves that are shallowly 5 to 7 lobed, and the individual lobes are themselves incised. The leaves are glabrous or have just a few hairs. The flowers are small, pink, with 5 petals. The fruit is an elongated capsule that dehisces explosively to disperse the seeds. The plants are generally glabrous, and mature plants have a distinctive reddish cast. The seeds germinate en masse in late summer or early fall after the first rains. Carpets of shiny cotyledons make established populations readily detectable when they germinate in the fall. The young seedlings are evident all winter, and produce flowers in mid-spring, with seeds dispersing in late spring or early summer. When mature, the fruits dehisce explosively, dispersing the seeds a short distance. Plants are completely dormant and are scarcely evident by mid-summer, even where they are abundant.

G. lucidum grows especially well in oak woodlands, but also can be found in dry conifer forests or riparian forests, generally in the shade. It tends to occupy somewhat drier sites than its equally problematic invasive relative, *Geranium robertianum*. The extreme abundance of *G. lucidum* at some sites, to the exclusion of other vegetation, suggests an allelopathic effect. It rapidly displaces native annuals, and also probably inhibits the recruitment of native perennial forbs. Presumably a seed bank is also formed where the species becomes established, because established populations tend to persist. The primary means of long-distance seed dispersal appears to be on the feet of livestock, deer, or hikers. *G. lucidum* has also established in landscaping associated with a stormwater treatment facility in Seattle where plants from a contaminated nursery in the Willamette Valley were planted (Antieau 2010).

G. lucidum is a major threat to the ecological integrity of oak woodland habitats. It was first collected in Oregon in Yamhill County in 1971. It has now spread throughout the Willamette Valley, and is beginning to spread south into the Umpqua and Rogue Valleys, and north into Washington. As of 2010, populations have been documented in Washington in Clark, Thurston, King, and Skagit Counties.

Mechanical Methods—Hand pulling of *G. lucidum* is easy because it is an annual with a slender taproot, but this treatment is probably useful only for new infestations in very small patches, because the plants often occur in populations of thousands to millions of individual plants, where hand pulling is not feasible.

Chemical Methods—*G. lucidum* can be treated with either glyphosate or triclopyr. Nonanoic acid (Scythe), a non-selective contact herbicide composed of pelargonic acid and other fatty acids, readily kills young shining geranium plants while "burning" the foliage of adjacent native perennial plants without killing them. This may be the most appropriate selective treatment for high quality natural areas.

Fire—A propane flaming device can be used on small patches of *G. lucidum* in the seedling stage. This can be done during the winter when the weather is often too wet for effective use of herbicides. There is no indication of any positive treatment effect of prescribed fire occurring during the dry season before the fall cohort of seedlings has already appeared.

All treatments need to be applied repeatedly at the site, beginning in the early fall and continuing through mid-spring, as new seedlings will arise from the seed bank to replace plants that are killed. Extreme care must be taken to find and destroy any plants that survive to flowering stage, so that they do not have the ability to add to the seed bank.

Observations and Outlook—Once fully established, *Geranium lucidum* is virtually impossible to eliminate from a site due to its rapid rate of increase, high plant density, persistent seed bank, and difficulty of implementing management treatments without causing collateral damage to associated native herbaceous species. Few, if any, botanists in the Willamette Valley recognized the threat posed by *G. lucidum* for the first two decades following its discovery, and at many sites it is now so abundant that eradication does not seem feasible. The possibility exists of control in selected areas through diligent EDRR programs, or of preventing establishment of new populations in natural areas, but early treatment and consistent followup is imperative to prevent the establishment of new populations. Now that scattered populations of *G. lucidum* have been discovered in Washington, it remains to be seen whether invasive species programs and natural area managers can prevent its full establishment throughout the WPG ecoregion.

Hairy Cat's Ear (*Hypochaeris radicata*)—*H. radicata* is a perennial herb in the Aster family that superficially resembles the dandelion (*Taraxacum officinale*). It has yellow flowers and oblong toothed leaves like dandelion, but the leaves tend to be very hairy. It grows from a deep taproot, forming a rosette in the first year and flowering by the second year of growth (GOERT 2009). Mature achenes are attached to a fluffy pappus of plumose bristles, which allows for long distance dispersal by wind.

H. radicata has been described as, "the most overlooked, ignored and invasive herbaceous weed in Garry oak ecosystems" (Brenda Beckwith 2005, quoted in GOERT 2009). It is very common in south Puget Sound and British Columbia grasslands, accounting for 10% cover or more in some areas (GOERT 2009, Gonzales and Clements 2010). Its impact on plant communities has not been well-studied, but it appears to be a strong competitor for water and nutrients (owing to its deep taproots). It may also release allelochemicals that could impact neighboring plants (Turkington and Aarssen 1983, GOERT 2009). Once a population of *H. radicata* is established in a location, it tends to persist.

Mechanical Methods—Hand pulling of *H. radicata* is difficult because it has a deep taproot along with several fibrous roots. Care must be taken to remove the entire root system while at the same time minimizing soil disturbance (GOERT 2009). Interestingly, *H. radicata* declined greatly in abundance in several Willamette Valley prairies in 2001 and 2005, which were years of high population densities of native meadow voles (in the genus *Microtis*) that apparently favor *H. radicata* as a food item.

Chemical Methods—In areas with sparse distribution, spot spraying with herbicides may be a viable option (GOERT 2009). Managers in south Puget Sound have used glyphosate, triclopyr amine, and aminopyralid with fairly good results. Aminopyralid appears to be most effective, but glyphosate is the most economical. Timing of application best follows a prescribed fire before native plants emerge. Without fire, careful application is necessary to avoid desirable natives. Treatments should ideally target one-year plants in the rosette stage.

Fire—Fire alone appears to favor the spread of *H. radicata* in many cases. It is one of the first green plants to emerge following a fire, which is an ideal time for herbicide application with minimal impact on native vegetation (Stanley et al. 2011a). Glyphosate is the herbicide of choice in this situation since it is inexpensive and does not persist.

Observations and Outlook—While *H. radicata* has been involved in studies of Garry oak native plant community restoration (Gonzales and Arcese 2008, Gonzales and Clements 2010), there is a need for more concerted research and management in Garry oak habitats in British Columbia. The plant exhibits the potential to continue to expand by colonizing currently unoccupied suitable habitats, and to increase its numbers in areas that it already occupies. *H. radicata* is a management priority in south Puget Sound, where it is also abundant.

Sulfur Cinquefoil (*Potentilla recta*)—*P. recta* is a perennial herb from the rose family with a simple or taprooted caudex and is native to southern Europe, north Africa, and west and central Asia. It has palmately compound leaves, grows up to 1 m tall and has pale yellow flowers. *P. recta* is a fire-adapted species, and a prolific seed producer. Plants are able to produce 4,400 seeds m^{-2} which are thought to be viable for a minimum of five years (Zouhar 2003). This species seems to prefer somewhat moist habitats. Most infestations are found along riparian corridors and seeds appear to be dispersed by water, vehicles, animals, and human foot traffic.

Mechanical Methods—Hand pulling is likely to be fairly successful for individual plants, but is not practical for larger infestations. Tractor mowing of infested areas should be done with care, and *P. recta* populations ought to be avoided, if possible, as the tiny seeds are easily dispersed. If mowing is necessary, it is advised that equipment be cleaned before moving to other locations.

Chemical Methods—Herbicide is the primary method used to manage *P. recta*. Aminopyralid and triclopyr appear to provide effective treatment. In 2007, monitoring points were established on south Puget Sound grasslands to determine the efficacy of *P. recta* following an herbicide treatment of 2.5% triclopyr amine with 0.25% Nufilm IR. The average stem count in 10-m treatment plots was reduced from 100 to 6 (The Nature Conservancy 2008). Despite these positive findings, triclopyr amine was replaced with aminopyralid after observing numerous plants bolting and flowering following triclopyr amine treatment. It is plausible this was due to poor application techniques rather than the effectiveness of the herbicide. Anecdotal observations indicate successful treatment may be obtained with aminopyralid, although no efficacy data are available.

Fire—Fire is not an effective means of managing *P. recta*. However, fire will stimulate seed germination, so it may be used in order to flush and exhaust a seed bank.

Observations and Outlook—P. recta is a tenacious, aggressive species that has the ability to flourish and dominate vegetation. At the present time this species occurs in scattered populations throughout the WPG ecoregion, but is still somewhat limited in extent. The number of documented infestations on Joint Base Lewis-McChord alone has risen from as few as 3 in 2001 to 169 in 2009, with some locations having hundreds or thousands of plants. In the Willamette Valley, it has been mistaken for a native species, *Potentialla gracilis*, and in this way has been propagated for restoration purposes and planted in native plant gardens. *P. recta* will need strategic, persistent management in the near future. EDRR is necessary for *P. recta* as one established plant can create an infestation that is difficult to eradicate. Land managers are urged to treat this plant as a very high priority.

Mouse-ear Hawkweed (*Hieracium pilosella*)—*H. pilosella* is a small rhizomatous and stoloniferous member of the aster family, native to Europe and northern Asia. It forms basal rosettes, and produces single stems, typically with a single pale yellow flower. *H. pilosella* is found on open prairie habitats, but prefers cooler, shaded areas such as beneath trees and Scot's broom shrubs. This tendancy for hiding under plants, plus the difficulty of finding it due to its small rosette that resembles *H. radicata*, makes it a challenging plant to manage. Repeated assessments of the infestation site are necessary while it flowers to ensure complete eradication. Anecdotal observations indicate that herbicide-treated areas can still produce viable seed because small, dense, and overlapping individuals preclude complete herbicide contact to all plants. *H. pilosella* produces seed that is wind-dispersed, but dispersal may also occur by transport of rhizome fragments.

Mechanical Methods—Persistent hand-pulling may be effective for small infestations of *H. pilosella*, but care must be taken to remove as much of the plant as possible and the collected material must be disposed of in a landfill. Repeated assessments of the infestation are necessary, and if any plants were missed and have gone to seed, then collection and disposal of the seed is necessary. Due to its short stature and the high risk of seed dispersal, mowing is not a viable method for *H. pilosella*.

Chemical Methods—Herbicide application is the primary means of managing *H. pilosella*. Both clopyralid and aminopyralid will kill it. In 2009, an experimental trial was established to compare the effectiveness of clopyralid and aminopyralid. Seven 1x1 meter plots were established for each herbicide; no controls were used because allowing any plants to set seed would be unacceptable. Plots were located on Joint Base Lewis-McChord in south Puget Sound and were treated mid-May. The total number of rosettes in each plot was counted prior to treatment, one month later, and one year later. Results demonstrated 100% control for both herbicides (The Nature Conservancy 2009). Aminopyralid was selected for use because it is believed to have a lower environmental impact. Even though effective chemical treatments exist, the difficulty of finding these plants is a limiting factor. When returning to treated areas, managers often find plants that have gone to flower or even set seed. In these cases, all flowers and seed heads need to be removed prior to herbicide application. A flowering plant that is sprayed can easily produce seed before it dies.

Fire—Response of *H. pilosella* to fire is not well documented. Anecdotal observation of a small isolated infestation on Joint Base Lewis-McChord that was burned in 2009 saw a sizeable reduction in plants the following year, but this success was certainly influenced by two years of herbicide application prior to the fire.

Observations and Outlook—The high success rate of chemical methods on *H. pilosella* may give the impression that this plant can be easily managed. Unfortunately, the plant's diminutive nature, wide flowering window, and ability to set seed after chemical treatment make this plant an extreme challenge. Early detection and rapid response protocols are recommended to any land managers that may find *H. pilosella*.

Carpet Burweed (*Soliva sessilis*)—*S. sessilis* is a very low-growing (often less than 2 cm high) winter annual, with many single-spined seeds that form a compact seedhead. This "bur" gives the species its common name, and perhaps facilitates dispersal via animals, but is also responsible for the nuisance aspect of the weed because infestations are painful when stepped on. The plant possesses fern-like leaves and small yellow-green flowers; it is generally difficult to detect when growing amongst other vegetation (GOERT 2009). Native to South America, *S. sessilis* has been introduced to parts of the western United States (particularly California) and southern British Columbia. It is found in Oregon and Washington but has only been recorded in Washington since the 1990s (Washington State Noxious Weed Control Board 2008) and its distribution and impacts have been studied much more intensely in British Columbia. In Oregon, this species is primarily coastal in distribution, but was also collected in the Willamette Valley in 2005. The first Canadian report was in Ruckle Park on Salt Spring Island in 1996. By 2005, it had been discovered growing at three other provincial parks, as well as a park in Victoria and a site in the Gulf Islands National Park reserve (Polster 2007). Once established, *S. sessilis* grows in large patches that may exclude other species, and thus threatens rare plant species in the area. In Garry oak systems, it tends to be associated with rare plants with similar seasonal phenologies (GOERT 2009).

Mechanical Methods—For hand pulling and other measures to be effective, a careful search of the area of infestation to ensure all major patches are targeted is required (Polster 2007). Once plants are removed, they need to be bagged and sent to a landfill (not composted) to prevent inadvertent spread of the seeds (GOERT 2009). Mowing is not an option due to the extremely low stature of the plant.

Chemical Methods—Although chemical treatments utilizing specific herbicides have been shown to have some efficacy against *S. sessilis*, resistance of *S. sessilis* to several compounds (i.e., picloram, clopyralid, and triclopyr) has been reported in New Zealand (GOERT 2009).

Fire—Propane torches have been utilized fairly extensively to treat larger patches of *S. sessilis* in British Columbia, especially where associated vegetation is considered expendable (Polster 2007). Prescribed burns might also be effective in reducing populations, but low intensity fires would likely have limited impact on populations (Fred Hook, City of Victoria, personal communication).

Since the discovery of the first infestation in British Columbia, fairly extensive efforts have been made to eradicate this plant in Canada, as it was thought to be a relatively recent arrival in the area, and there might be an opportunity to eradicate it. Shortly after the BC Invasive Plant Council was formed, it supported the launch of an early detection program for *S. sessilis* as a test case. Over 175 sites were searched by the two search teams in 2006. *S. sessilis* had been found at 23 sites by 2006 (Polster 2007). At these 23 sites, small patches were pulled and larger patches were burned using propane torches. Despite these efforts, the number of sites continues to increase. Efforts continue to attempt to eradicate *S. sessilis* at the original site at Ruckle Provincial Park on Salt Spring Island through yearly monitoring and hand-pulling (Sally John and Jean Brouard, Isabella Point Forestry, personal communication, 2009). The presence of *S. sessilis* continues to threaten rare plants at this location. An area was quarantined around the original infestation at Ruckle Park to try to prevent spread, but many other populations have been found on the site outside the quarantine area (Sally John and Jean Brouard, Isabella Point Forestry, personal communication).

Efforts to manage *S. sessilis* in other locations in British Columbia have also been ongoing. In 2006, two sites in Beacon Hill Park in the City of Victoria were burned with propane torches, fenced for exclusion of people and dogs, and overseeded with Kentucky blue grass (*Poa pratensis*) (Fred Hook, City of Victoria, personal communication). The intention was to see if *S. sessilis* would be outcompeted by heavy grass growth. By 2008, no more S. *sessilis* germinants were found outside the exclosures. Sections of these areas will be burned off and other sections mowed in the fall of 2010 to evaluate whether *S. sessilis* has persisted via seed bank. Six additional outbreaks have been located in Beacon Hill Park since 2006. The five smaller ones (< 20 cm in diameter) were eliminated by burning. The sixth, discovered in 2008 and approximately 1x7 m, was reduced to 5% of the original size by burning by 2010. Depletion of the seed bank over the wet spring of 2010 may have also reduced populations.

Observations and Outlook—Although some success has been achieved in containing the spread of *S. sessilis* in British Columbia, without sustained and coordinated efforts by agencies and volunteers, the plant is destined to become much more numerous and represent a substantial threat to Garry oak systems because it is very well-adapted to open areas with a Mediterranean climate. It is a good example of the value of developing EDRR programs. Even though it continues to spread, many British Columbia residents are watching for it and are aware of the problem. Unfortunately, it already appears to be widely distributed across many sites in western Washington, where it is listed as a Class B Noxious Weed (Washington State Noxious Weed Control Board 2008). Relatively little effort has been expended on monitoring and managing its spread in Washington compared to British Columbia, making burweed a good example of how improved coordination of efforts across the region could greatly facilitate invasive weed management.

Knapweeds, Star-thistles (*Centaurea* spp.)—All *Centaurea* species in North America are introduced from Eurasia or north Africa, except *C. americana* and *C. rothrockii,* which have recently been placed in the genus *Plectocephalus.* Nomenclature of centaureas has historically been problematic and confusing, in part because different names have been applied to different taxa by different authors with varying definitions, and partly because they can be difficult to identify as most species are capable of hybridizing and producing considerably variable progeny (eFloras.org 2011). Several species are highly invasive, negatively impact habitats at the landscape level across the Pacific Northwest, and are listed as noxious weeds across much of Canada and the United States (Boersma et al. 2006). As all of the *Centaurea* species that occur in the WPG have similar growth and reproductive mechanisms, and because they respond similarly to management actions, they are treated collectively here. Species that are known to occur in the WPG that require management action include: spotted knapweed (*C. stoebe* syn. with *C. maculosa, C. biebersteinii, and C. rhenana*), diffuse knapweed (*C. diffusa*), brown knapweed (*C. jacea*), black knapweed (*C. nigra*), meadow knapweed *(C.* ×*moncktonii* syn. *C. jacea* var. *pratensis. C. jacea subsp.* ×*pratensis, C. pratensis* (misapplied)), Maltese star-thistle (*C. melitensis),* and yellow star-thistle *(C. solstitialis*). *C.* ×*moncktonii* is a fertile hybrid between *C. nigra* and *C. jacea*, and has been the result of much of the taxonomic confusion. The Flora of North America now recognizes *C. jacea, C. nigra*, and *C. nigrescens* as three separate species and includes a new species, *C.* ×*moncktonii* as part of the complex, though they note that these could be treated as a single species (*C. jacea*) with several subspecies. *C. solstitialis* is poisonous to horses when ingested over a prolonged period. *C. ×moncktonii* is by far the most aggressive of WPG knapweeds and is capable of spreading exponentially in a single season if left untreated.

Centaurea spp. are annual, biennial, or short lived perennial members of *Asteraceae*. Some species (e.g. *C. diffusa*) can behave as all three. They grow up to 1 m tall and have flowers that resemble small thistles growing at the end of clustered branches (Boersma et al. 2006). Flower colors include white (*C. diffusa*), pink/purple (*C. diffusa, C. stoebe, C. jacea, C. nigra, C. ×moncktonii*), or yellow (*C. melitensis, C. solstitialis)*. Seed production ranges from a few seeds (rarely) to about 2,000 per plant, depending on conditions. *C. stoebe* plants in Washington and Idaho averaged 23 to 61 flower stems per m^2, 11 to 16 seedheads per stem, and 24 to 33 seeds per head, producing 11,300 to 29,600 seeds per m^2 (Shirman 1981). Most species lack elaborate pappi to facilitate wind dispersal. Therefore, achenes usually drop within close proximity to the parent plant. Several species have long-lasting viable seeds with the ability to stagger germination over several years, and some may possess allelopathic properties (Boersma et al. 2006, Kaufman et al. 2007). The primary reproductive method is by seed. However, some can produce lateral rosettes from underground roots. *Centaurea spp.* are favored by bees, which results in high seed viability, thus promoting their proliferation.

Generally speaking, killing individual knapweed plants is relatively easy; they respond well to most herbicides and are relatively easy to detect because of their showy flowers. However, controlling seed set for this genus is imperative; areas where plants have seeded for one year will require many years of follow-up treatment.

Mechanical Methods—Hand pulling is only recommended when herbicides are not an option, though it is unlikely to kill the plant unless all the roots are extracted. Hand pulling should only be used to control seed-set in small infestations if the plant has started to senesce and will not respond to herbicide. It is essential that all flowering heads are removed and disposed of properly as many members of *Asteraceae* are capable of setting viable seed after they have been pulled or cut. It is recommended that gloves are worn as plants may contain alkaloids that produce skin irritations.

Mowing is temporarily effective at reducing seed set but flowering heads must be collected and removed from site. Depending on timing, mowed plants might have the ability to resprout, flower, and set seed during the same year. In these instances, they flower as dwarf individuals that make detection more difficult (Thorpe et al. 2009). Repeated mowing should primarily be used in areas that have no native component as mowing at the time of year that would be effective would also impact native plants.

Chemical Methods—Herbicides are the primary method of managing *Centaurea spp*. Glyphosate has proven effective at Joint Base Lewis-McChord, especially on first year rosettes and early growth stages of mature plants. However, if flowers have been or are close to being produced, the use of faster acting herbicides are required (such as aminopyralid or triclopyr amine, both proven to be effective). It is essential that flowering heads that are close to fruiting are cut and removed, no matter which herbicide is used.

Biological Methods—There have been 13 biological agents released on knapweeds in the past five decades, with some success. Two strains of seed head fly reduced the number of seeds per flower head in populations of spotted and diffuse knapweed between 64% and 80% in different study sites (Maddox 1982). Most agents attack either the flowering heads or roots, and some rusts have shown promise at reducing foliage. However, risks associated with release of the control agent are often not often fully understood. Some agents appeared to actually do more damage to adjacent *Festuca idahoensis* plants than to knapweeds in one study (Calloway et al. 1999) and others can alter habitat selection and diet in field mice to favor host larvae, which can negatively affect the efficacy of the host agent (Pearson 2003).

Fire—Late-summer prescribed burns are not effective at managing knapweeds because many individuals have already senesced and set seed. Annual summer burning while the plant is in flower is the only effective timing interval between burns that was effective. Fire can sometimes reduce seed bank longevity, especially at high intensities that cause soil heating (Emery 2005). Late summer burns may deplete seed banks by encouraging germination, and might make other management options more effective as the plants are more readily visible and accessible. Annual late spring/early summer prescribed burns can reduce cover by reducing seed set over time and kill mature plants. However, this can potentially have negative impacts on native plants in habitats with a native component.

Other Methods—Additional options for management include mulching, grubbing, or covering with opaque landscape fabric. All three methods have demonstrated some success, especially when treatments were combined. Covering occupied habitat with opaque landscape fabric for one year will kill all live plants and potentially some seed if temperatures are high enough. When combined with mulching and sowing of native seeds, covering with opaque landscape fabric produced a reduction of introduced species of between 30% and 60% (Thorpe et al. 2009). All three methods are labor intensive and would not be suitable for habitat with a native component, or where knapweed plants are interspersed with woody vegetation, and would not be feasible where infestations cover a considerable area.

Observations and Outlook—Knapweeds are some of the most widespread and invasive species in the Pacific Northwest and are especially problematic and persistent on Joint Base Lewis-McChord's prairies. In the Willamette Valley, meadow knapweed actively threatens prairies occupied by the federally threatened Kincaid's lupine and endangered Fender's Blue butterfly. The ease with which its seed is able to be moved by humans and wildlife ensures that new populations will continually be established. Sites that have had long-standing populations will take years to exhaust the seed bank. Perseverance and vigilance can reduce the size of most populations over several years, and ERDD efforts at several Willamette Valley prairie preserves have proven effective at preventing small patches from establishing and spreading. However, allowing one plant to set seed will require several additional years of treatment. Thorough and repeated surveys through the summer months will ensure that new populations are detected early enough to prevent seed set.

Conclusion

Natural area managers in the WPG face the reality that pressure from invasive plant species will be incessant for the foreseeable future. Land managers are challenged to respond to these invasions with prioritized, aggressive treatment strategies, while also minimizing impacts on native flora and fauna. Since managers have limited resources, it is important to strategically prioritize and sequence the species and sites treated, as well as respond rapidly to new invasions.

Management of invasive plants is a dynamic process that requires careful consideration of plant phenology, impacts to non-target plants, and the vegetative response of both native and non-native plants to the increased availability of open soil. An area that is dominated by invasive plants will most likely be dominated by invasive plants after treatment unless desirable native plants are seeded or outplanted. For this reason, a comprehensive restoration strategy that includes both invasive removal and establishment of natives, either from seed or plugs, is critical to restoring natural areas. The true goal of a restoration program is not just the removal of problematic species, but a functional and vibrant native community.

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