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Airway Heights, Washington
February 10-13, 2014

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Edited by:
Mark Schwarzländer and John F. Gaskin

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FOREWORD

The Northern Rockies Invasive Plants Council (NRIPC, www.nripc.org) is a non-profit organization founded in 2008 with the goal to support the management of invasive exotic plants in the northern Rocky Mountain States by providing a forum for the exchange of scientific, educational and technical information. This meeting was the 3rd Conference organized by the NRIPC towards fulfilling its mission to facilitate exchange directly between those groups and individuals involved in invasive plant research and invasive plant management. Through the past conferences the NRIPC's goals have been extended to address priority invasive problems within covered states through dedicated symposia, and the conferences have become among the largest regular gatherings of researchers and practitioners involved in biological control of weeds. Papers presented at the 2nd NRIPC conference and subsequent discussions of conference attendees have resulted in the preparation and publication of three refereed review documents in the Journal Invasive Plant Science and Management. Since it was anticipated that the demand for print products would increase, the NRIPC decided to produce its own proceedings for the 3rd Conference. This document illustrates the efforts of the many individuals, agencies and companies who provided funding for the conference, those who organized the meeting and provided presentations, the authors and author teams who took on the task of preparing manuscripts and the peer reviewers who provided feedback and edited the six full papers presented here. These proceedings illustrate the dynamics of information exchange achieved by the NRIPC and showcase the width and depth of topics brought and collaboratively discussed at the NRIPC Conferences.

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PROGRAM COMMITTEE

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CONTENTS

Presentations

Publications

Reframing the Social Values Questions that Underlie Invasive Plant Conflicts: Issues to Consider for Russian Olive

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ABSTRACT

Social values shape human perceptions of invasive species and control efforts against them. Social values can influence the success of proposed control projects, especially biocontrol projects. Twenty years after finding an appropriate biocontrol agent for *Psidium cattleianum* (Strawberry guava), arguably the worst pest in Hawai'i's rainforests, and 8 years after applying for federal release permits, no release has occurred. In contrast, a permit for releasing an exotic pathogen targeting *Nassella neesiana* (Chilean needle grass) in New Zealand was granted after a review period 68 of days. These cases point to the importance of social values in the control of invasive plants. Invasive species control, including biocontrol, is a public interest science, which suggests the importance of collaboration with the public, or at least garnering some public input. Invasive species control projects, undertaken in the public interest, should be subject to some form of participatory public engagement. Many invasive species control projects are undertaken from a stance of prudence, the ability to anticipate what positive results could come from actions taken today. Fostering public engagement and social learning about invasive plants and the social values associated with them increases the likelihood of success of any control project, whether or not the project includes discussions of a novel biocontrol agent.

INTRODUCTION

Invasive species control is simultaneously an economic and ecological act, and ultimately an ethical act as well. The science of weed biocontrol was originally developed for pragmatic economic purposes: classical biocontrol, when it works, is cheaper and more economically efficient than mechanical or chemical control. It has the potential to be the most sustainable solution to weeds. Later, as the negative effects of widespread agrochemical use became apparent, weed biocontrol became more attractive for ecological and ethical reasons. However, invasive species control efforts take place against the backdrop of broader social debates about limiting the role for governmental agencies, whether for programs or regulations. Government funded environmental initiatives are under great scrutiny. If any control project is conducted by public agencies, this is a political act too. This raises questions about political philosophy: what is the role of social values in public agency-sponsored environmental research, management and regulation?

I do not propose to directly answer these philosophical questions, nor to dictate moral principles in any way. However, this presentation will focus attention on the critical importance that social values play in framing invasive plant control programs, and the influence they have on the outcomes (Warner, 2013). The following metaphor may provide insight: social values are akin to the staging of a drama. They underlie the play. Social values are not the actors, not the heroes nor villains. Social values are the stage itself, the props, and the lighting. They shape the narrative tone, the coloring of the drama and performers. They influence how the audience perceives the entire production.

To this end, I will begin with the story of two weeds: two control projects that have unfolded in entirely different ways, in part due to social values. I will then propose public interest, public participation, and prudence as values to guide invasive species control projects. I will conclude by recommending how to construct consensus around the control of Russian olive, although these recommendations have implications across many kinds of invasive species control efforts. This presentation will give particular emphasis to biocontrol of plants, since that practice has stirred some of the most active public debates.

2. A tale of two weeds

The social context of weed biocontrol has changed dramatically since this practice was first developed. Formerly, biocontrol researchers labored in autonomy from society, but now they are increasingly expected to communicate their work to non-expert public officials and members of the public. Conflicts over biological control releases between different interest groups first emerged in the 1980s, first over the potential release of phytophagous insects. In eastern Australia, pastoralists requested work be done to control the invasive plant *Echium plantagineum* L., which they named "Paterson's Curse" because it is toxic to cattle. Beekeepers had named the same plant "Salvation Jane" because it survives drought in some spots and because it provide a key source of nectar and pollen for bees. The conflict between these economic interests led Australia to pass the first (and still the only) dedicated Biological Control Act in 1984 (Cullen and Delfosse, 1984). In the Pacific Northwest of the United States, concerns were initially raised about the potential impact of biocontrol agent releases shifting hosts from the intended target of *Euphorbia esula* to native spurges (Pemberton, 1985). Sustained public controversies over the biological control of Carduus spp. (Louda et al., 1997) and Tamarix spp. (Bateman et al., 2010), and the high associated costs of these controversies, demonstrate that the relationship between the public and those who lead invasive species control efforts requires a fresh approach. In the 21st century social context, unidirectional communication to or from the public regarding science is not sufficient to garner public monies, nor public support, for any type of environmental management activity (Larson, 2005).

2.1 *Psidium cattleianum*, aka strawberry guava, in Hawai'i

Horticulturalists introduced the strawberry guava tree (*Psidium cattleianum*) to Hawai'i as an ornamental plant in 1825, and it quickly began to spread into native forest. Released from its native range natural enemies in the neotropics, it became more vigorous and able to form monotypic stands that suppress Hawaiian understory plants -- and the fauna that depend upon them. Local Hawaiians have given it a native Hawaiian name, "waiawi." Few members of the public realize it is not native. Strawberry guava is in the same plant family as common guava (Psidium guajava), the agricultural crop tree, although the strawberry guava fruit is very small, difficult to harvest, and of no commercial value (Wikler and Smith, 2002).

P. cattleianum was identified as a grave threat to Hawaiian forest ecosystems in 1978, and is one of the most disruptive invasive plants of tropical and subtropical islands worldwide (Denslow, 2003; Wikler and Smith, 2002). It has been called the "worst pest in Hawaii's [sic] rain forests" (Smith, 1985) and is widely recognized within the Hawaiian conservation community as such. The following is a timeline of efforts to control this weed (for details, see Warner and Kinslow, 2013).

1985. Biological control was identified as the only viable strategy for long-term control of *P. cattleianum* (Smith 1985).
1991. Exploration for potential biological control agents in Brazil was begun.
1993. A candidate agent was identified in the field. Researchers identified *Tectococcus ovatus* as a scale

insect that would form galls exclusively on *P. cattleianum*.

1999. Laboratory testing began in Hawai'i, confirming that *T. ovatus* could only attack the target tree and no other species. Heavy infestations of the insect can kill branches or even trees, but generally it results in disfigurement and reduced reproduction.

2005. Application for Federal permits.

2007. Federal permits received.

2007-8. Multiple permit hearings held in Hawai'i to comply with state law, with no objections raised.

2008. Application for final state permit submitted. A contrarian activist organizes local opposition, resulting in more hearings and delays.

2010. The writing of a new Environmental Assessment document.

2014. No release yet.

There are a number of unusual local factors at play in Hawai'i, but here I wish to highlight elements of invasive plant control projects that have broad lessons for other locations, and have the potential to inform control projects targeting other woody invasive plants, such Russian olive.

First, a non-native tree was introduced for an aesthetic purpose many decades ago. Most members of the lay public assume it "belongs" in this place. The scientific community that recognizes this as a woody invasive causing ecosystem-level problems cannot assume that the public has this knowledge. In the case of *P. cattleianum,* the plant escaped, but with Russian olive, the tree was introduced with the encouragement of government officials. In this case, many perceived the plant to be a part of the native Hawaiian forest, and could not understand why it needed to be controlled. The harm caused by an exotic plant was not apparent to ordinary members of the public. Effectively communicating to the public the harm caused by species like *P. cattleianum* is a necessary precondition for proposing a management action such as releasing a novel biocontrol agent.

Secondly, some members of the public do not trust government scientists, either because they work for the government or because they are scientists. In this case, the scientist was guilty by association: he worked for the Federal government. He was called all kinds of names by angry members of the public. There were few compelling voices with credibility in the community speaking in favor of the biocontrol project, leaving the project without an advocate. However, at the end of the day, the salient facts as of this writing are: millions of research dollars later, 20 years after discovering a target-specific biocontrol agent, and 8 years after applying for and 6 years after receiving a Federal permit for release of the agent, no biocontrol agent has been released against *P. cattleianum*. Identifying credible messengers to communicate effectively to and responsibly with the public is essential when managing an invasive species project with any tinge of controversy.

2.2 *Nassella neesiana*, aka Chilean needle grass, in New Zealand

This weed, a native of South America, has invaded managed pastures and natural grasslands in Australia and New Zealand (Anderson et al., 2010). A biocontrol project, assessing plant pathogens, was jointly undertaken by these countries. After a decade of testing, *Uromyces pencanus*, a rust native to Argentina, was identified as the most promising candidate. It caused significant damage in the field, but only on the targeted weed (Anderson et al., 2010; Anderson et al., 2008). One might think that a plant pathogen would inflame public opposition based on risk fears (Warner, 2012). The government of New Zealand issued a permit for release of this pathogen as a biocontrol agent in 68 days (Hill et al., 2013). This is the shortest public agency permit review period for any proposed biocontrol agent anywhere within the past two decades.

There are a number of fortuitous social factors that eased the permitting review process in New Zealand. First, the country is composed by a cluster of islands very far from other land masses, resulting in a distinct national identity with a shared commitment to biosecurity (Goldson et al., 2010). Second, there is widespread awareness of the environmental problems caused by invasive plants, and broad support for their control, expressed by local governments, with the support of taxpayers (Hayes, 1999; Hayes et al., 2008). Third and most important, at the national level, New Zealand's legislature created a transparent, democratic, and ecologically informed approach to biological control agent introductions (Barratt and Mooed, 2005). The Environmental Risk Management Authority (ERMA) regulates all novel organisms and hazardous substances, including the introduction of biological control agents (Barratt et al., 2010; ERMA New Zealand, 2010). ERMA has the world's most sophisticated decision-making process for evaluating biocontrol agents. It developed clear decision-making criteria based on transparent and replicable ecologically-based risk/cost/benefit analysis, fixed time periods for decisions, and participatory public engagement (Harrison et al., 2005). All applications for and ERMA decisions regarding biological control introductions are posted on the WorldWideWeb.

The review process created by ERMA balances multiple scientific and social criteria while requiring applicants for a release permit to conduct public consultation before requesting a permit (ERMA New Zealand, 2010). General social value questions were incorporated into the legislation, intended to require all parties to address specific social values issues at the outset of a proposed introduction, and through democratic deliberative processes. In the case of biological control introductions, the benefits must be considered, and weighed, against risks of harm (Harrison et al., 2005). In New Zealand, scientists are not applicants for permits. Instead, the land management agency is the petitioner, and these organizations fund research agencies to conduct the pre-release testing, and fund consultants to facilitate public outreach. This removes the research scientist from the situation in which he or she is vulnerable to perceptions of professional conflict of interest in advocating for a release. Petitioners must demonstrate that they have consulted affected members of the public, including Indigenous Maori communities (Hayes et al., 2008). By requiring consultation with affected communities before submitting an application, petitioners can receive early feedback from those who have concerns about the proposed introduction. Stakeholders and scientists report that the ERMA review process has prompted broader and more explicit consultation and review of invasive species targeted and discussions of potential risks before any application is submitted.

ERMA's risk/cost/benefit approval criteria are difficult to fulfill but quite clear: benefits must be scientifically demonstrated to outweigh risks and costs. Early in the application process, ERMA advises the applicant how to demonstrate fulfillment of these criteria, but ERMA is bound by a fixed schedule for making a decision by statute. ERMA's success as an environmental policy and decision making instrument prompted the national legislature to adopt it for the national Environmental Protection Agency, which subsequently absorbed the original ERMA unit (Hill et al., 2013).

3. The public, values and invasive plant control

3.1 Invasive species control is a public interest science

All forms of scientific practice that pursue a social or environmental goal are necessarily ethically laden, meaning that it is linked to a social choice (Shrader-Frechette and McCoy, 1993). Conservation biology in its origin and by its orientation is an ethically laden science, but so too is any effort to use science to control invasive species, including the practice of biocontrol. Conservation science, biological control, and the science of biological invasions all claim to act in the public interest, on behalf of the public, and thus to be public interest science. Raffensperger et al. (1999) proposed three criteria to define public interest science: (1) Research is conducted with input from or in collaboration with the public or an active citizenry, (2) Research products are made freely available (not proprietary or patented), and (3) The primary, direct beneficiaries are society as a whole or specific groups unable to carry out research on their own behalf. By this definition, public interest science necessarily relies upon some expression of public consent and results in a non-commodity product (Warner et al., 2011). In other words, points 2 and 3 are inherent to invasive species control, suggesting the importance of attention to points 1. Any scientific community claiming to work on behalf of the public has a collective professional ethical responsibility to engage the public: to explain and listen to, and exchange information with, members of the public or organizations that represent the public. Since public monies fund most invasive species control programs through taxes, it is reasonable to expect scientists to inform, educate and engage the public on a continuing basis. Since conservation biology, invasive species control, and biological control are all public interest sciences, practitioners need more than passive public acquiescence to succeed today.

The social value of democracy proposes that increasing public participation in decisions that affect the public will result in better outcomes and more support for the substance of the decision itself. The effective articulation of science, democracy, and social values is not a simple problem, yet balancing criteria from these three sources is critical for any public interest science. Without some expression of public support, a community of scientists cannot legitimately claim to be acting in the public interest. In the case of Russian olive, it will be important for some stakeholders to clearly elaborate the economic and environmental harm of this invasive plant -- assuming the evidence exists. Scientists and economists play critical roles in documenting and analyzing the harm, but other parties need to be those who argue that control is in the public interest. This is especially true when the proposed target was once introduced purposefully by public agencies.

3.2 Democratic values are expressed through public engagement

Scholars of science policy have articulated a new decision-making framework for relating scientists and their institutions to society: participatory public engagement with science and technology (hereafter shortened to "public engagement;" McCallie et al., 2009). Public engagement processes facilitate mutual learning among the public, scientists, and regulatory officials with respect to the development and application of science and technology in modern society (Mooney, 2010). Public engagement is a semi-structured transparent deliberative process that establishes consensus views on evidence, method, interpretation, and social values frameworks as the basis for making a scientifically-informed decision (Rowe and Frewer, 2005). Public engagement initially appears more costly in terms of time and resources. However, as the examples of biocontrol controversies above demonstrate, the costs imposed by years of conflict and delay may be even greater.

Public engagement processes allow scientists to speak directly about conservation and the need for environmental management actions, but requires scientists to communicate environmental conditions and a rationale for any conservation action (involving biological control or not) in terms that can be understood by non-scientists. Public engagement differs from public hearings in that it requires bi-directional communication between scientists, public decision makers, and lay publics (McCallie et al., 2009). It is a deliberative "dialogue" in which publics and scientists both benefit from listening to and learning from one another, which can be described as mutual learning. Public engagement requires members of the public to do more than question experts. It requires scientists to do more than merely present their expertise and findings. Public engagement requires lay publics to learn about science and policy, and requires scientists to learn what members of the lay public know and don't know about science, but also about peoples' beliefs and social values. Participants from a variety of perspectives participate over a sustained period of time, guided by shared goals and agreed upon guidelines for respectful communication. One practical value of this kind of process, if designed well, is that it brings to the table those who have the strongest opinions, pro and con, prior to a specific decision or action. This facilitates engagement before a public agency decision point, which is a key strength of public engagement approaches. In the case of Russian olive, it would be very helpful to identify and engage those who do not support, or will resist, efforts to control the invasive species -- before any decision looms.

Many scientists and public agencies are reluctant to engage the public and the media for very good reasons: they do not want to have scientific evidence put to a vote, engage in arguments with non-scientists, nor have their conclusions sensationalized. However, the cumulative effect of individual scientists and agencies not effectively communicating with non-scientists perpetuates the problem of public misunderstanding of environmental problems and solutions (Mooney, 2010). To address large-scale invasive plant problems in the 21st century, scientists and stakeholders must do more than hope for passive public permission. To succeed, they will need to cultivate active public support, as is seen in New Zealand.

3.3 Prudence points to the value of invasive plant control management actions

The ethical justification for expending resources or taking action against an exotic species that is expanding its range is grounded in prudence, the ability to anticipate the likely future outcomes of present realities and make wise choices with this foresight. Prudence proposes the responsibility to act today based on knowledge of likely future events. For example, the decision to release a classical biocontrol agent is based not only on extant evidence of harm, but also in anticipation of scientifically-predicted economic and ecological disruption. In this context, decisions today are informed by scientific models and statistically-informed predictions, which are sophisticated beyond the understanding of an average citizen. Prudence is a particularly relevant social value, or ethical principle, to discuss in the context of public engagement, because initiatives to control invasive plants operate with a relatively long time frame and require some degree of expertise. Prudence may require actions that involve some risk, just as responsible health care may require intervention in the form of surgery before the full range of symptoms are present. When scientific experts engage the public, it is important for them to simultaneously explain their data and models, but also, in recognition that they are proposing an action with social implications, to discuss social values that are relevant to the proposed action. Prudence is a social value that can foster public consensus in support of invasive species control initiatives.

4. Principles to frame social values in support of invasive plant control

4.1 Most members of the public are not interested in invasive plants, but some really are

There is little return on generic efforts to reach out to generic publics. Instead, public engagement strategies suggest public agencies should identify, reach out to, and convene all likely interested stakeholders, especially possible critics. For public engagement to succeed, it is essential to begin by identifying stakeholders with strongly held opinions, pro and con, and to convene them in a dialogical process. Stakeholders with strongly held opinions -- but are unknown to those leading biocontrol projects -- are those most likely to contest and delay biocontrol projects. For example, Australia has an on-line stakeholder registry, and New Zealand actively encourages public comments on proposed introductions.

4.2 A public process should enhance the capacity of all stakeholders to understand science and agency decision-making processes

For public engagement to succeed, it must convene a structured co-learning process in which everyone, from critics to supporters, participates over time in grasping the same scientific information about the invasive species and possible control methods (Woodhill and Röling, 1998). Public engagement fails if parties have divergent information about a problem and its possible remedies. Most public concerns about biocontrol are founded, at least loosely, on conservation values, such as: is the invasive plant really a problem?; why introduce another organism?; what other organisms will the agent attack?; and what will the agent do when it consumes all its hosts? These questions have a scientific but a democratic dimension as well, because concerned citizens want to be heard and have their concerns respected. Few stakeholders are able to play any kind of constructive role with only the knowledge that they bring to such a process, therefore, education of stakeholders is integral to any kind of engagement. For example in New Zealand, efforts to engage Indigenous Maori communities have dealt with biocontrol issues chiefly from the perspective of cultural and ethical values, and not biology, however, they have been relatively successful because everyone's opinion is dealt with respectfully (Hayes et al., 2008). As a result, New Zealand scientists and their institutions have learned about the social values of their fellow citizens, and how to best engage those values to take actions in the public interest.

4.3 Beneficiaries -- stakeholders, not researchers -- should explain why control of the invasive species is in the public interest

When invasive species cause direct economic harm, those who wish to alleviate that economic harm are potential beneficiaries. When invasive species cause harm to ecosystem function or endangered species, human organizations must be able to speak on behalf of their conservation. Conservation groups should, ideally, speak on behalf of the public or society at large. When scientists develop expert knowledge about an invasive species problem and then speak in favor of a specific management action, they expose themselves in public to the perception of bias, also known as professional conflict of interest. Scientists should not risk being viewed as an advocate for a control project. Creating greater consensus on the need to take such conservation actions is a critical first step that is fundamental to success in invasive species control. For example, Australia has a national weeds strategy that prioritizes target weeds (Natural Resource Management Ministerial Council of Australia, 2007). In New Zealand, regional councils serve as critical institutional intermediaries between taxpayers as stakeholders with research institutions (Hayes, 1999), and extend economic arguments favoring invasive plant control. This insulates researchers from public suspicions of conflict of interest, i.e., that the researcher might lose objectivity by promoting a project that advances his or her career. In the United States, public/private coalitions of stakeholders can speak on behalf of the public's interest in invasive species control. In New Zealand, regional councils articulate an economic justification that makes clear the advantages of biocontrol over other forms of control to tax payers. In the New Zealand regulatory system, these regional councils are generally those who petition for invasive plant biocontrol release permits, and they are better positioned to articulate these advantages, and to engage in discussions over conflicts of interest. These regional councils represent the public better than a scientist can, so the scientist serves as scientific expert advisor, and never the advocate for controlling a pest (ERMA New Zealand, 2010). Legislation imposes the burden of public consultation and engagement on the petitioner for a permit. Although this appears costly, in practice it appears that this is more than offset by decreased costs and conflicts associated with the actual regulatory decision (ERMA New Zealand, 2010). Other countries could benefit from this approach, although in the US, it would require going beyond what is required by law.

4.4 Advocacy for invasive species control should be distinguished from selection of specific control strategies

Organizations, individuals, communities, or stakeholders should speak to the broader public about the need for controlling an invasive species. The problem of invasive species, defined as a problem by scientists, needs to be explained to the public in a way that is meaningful to a non-scientist, and the public should express some form of consent to the value of controlling the invasive species before any specific management action is proposed. Without some expression of concern about the problem of invasive species by members of the public, invasive species management cannot be a public interest science. This creates a social context supportive of expert decisions regarding specific management practices, such as biocontrol.

4.5 Public agencies should articulate their decision-making criteria clearly and gather stakeholder input on how best to apply these criteria to specific management actions

The New Zealand permitting system is efficient because any decision to release a biocontrol agent is made on a very clear, specific, and objective basis. It requires evidence of prior public engagement with the problem of targeting the invasive plant and the suitability of a specific biocontrol agent. Then, the question upon which the decision is made is simple (as in straightforward): are the anticipated benefits greater than the costs and risks? This is a practical expression of prudence in invasive species control. In New Zealand, this has frontloaded costs and public engagement efforts, but has made release decisions less contested.

CONCLUSION

Social values influence the success or failure of invasive species control projects, especially biocontrol projects. Control of invasive plants is, at least in theory, a public interest science. It is chiefly funded by governments and is done on behalf of the public. Some expression of public support is necessary for a public interest science in a democratic society. Invasive species control projects, undertaken in the public interest, should be subject to some form of participatory public engagement. Many invasive species control projects are undertaken from a stance of prudence, the ability to anticipate what positive results could come from actions taken today. Fostering public engagement and social learning about invasive plants and the social values associated with them increases the likelihood of success of any control project, whether or not the project includes discussions of a novel biocontrol agent.

Public engagement can be structured so that it enhances public stakeholder support for biocontrol of invasive plants without imposing burdens upon researchers. However, lessons of prior public engagement suggest that scientific research activity should not be confounded with advocacy for invasive plant management. Fostering social consensus on the need to control the invasive plant is a pre-requisite. Public engagement requires careful attention to devising appropriate roles for stakeholders, and nodes for public input in decision-making processes. Greater public engagement with biocontrol of invasive plants can be achieved by disambiguation of problem definition from solution options, and research activities from stakeholder advocacy and public deliberation.

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Revegetation after Russian-olive (*Elaeagnus angustifolia* L.) Removal Along the Yellowstone River: a Cost and 2-year Success Assessment

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ABSTRACT

Restoration can improve sites that have been degraded by weed invasion and prevent secondary invasion by pre-empting niche space away from these unwanted colonists. We removed Russian-olive trees from a 1.9 ha site along the Yellowstone River in 2011 and installed a controlled revegetation experiment in 2012. Russian olive resprout rates in the year of removal were 4%, but sapling kill was necessary in the two years following removal because seedling recruitment would have generated a 21% population replacement rate in the first year and 10% in the second year. Survival of transplanted native trees and shrubs was high (64%± 32 SD), even though the year in which we transplanted was one of the driest on record. Seeding the herbaceous layer also resulted in increased numbers of desirable species in the plots, but plant cover was very low. Our restoration was planted into mostly bare ground because there was little understory vegetation prior to removal due to the heavy shading of Russian olive and because our removal method of a tree shear on a skid steer created surface soil disturbance. After weed removal, conversion of bare ground to a functional native plant community that is capable of resisting other plant invasions often takes many years.

Key Words: riparian, revegetation, invasion, regeneration

INTRODUCTION

Riparian areas have been heavily utilized for agriculture for centuries as they often represent the most productive area in any landscape. Riparian corridors are unusually diverse and are significant contributors to regional biodiversity (Naiman et al., 1993). Because of the high contribution of riparian vegetation to ecosystem services, invasive species in riparian areas may be particularly damaging as dominant invasive species change community structure beyond their population boundaries (Gordon, 1998). We know very little about how community function changes after dominant invasive species are removed (DeMeester and Richter, 2010). Invasion of secondary weeds often follows eradication of a primary noxious weed species (Denslow and D'Antonio, 2005; Rinella et al., 2009), and the resulting plant communities can be so heavily modified that native consumer species such as birds and arthropods avoid these areas (Nelson and Wydoski, 2008; Sogge et al., 2008). Here we show the short-term effects of Russian-olive tree removal and revegetation on plant communities. This report is a circumscribed, short-term assessment of a long-term study that examines the value of Russian olive removal and restoration to soil quality and arthropod communities as well as to economic variables such as forage quality.

Revegetation is a cultural activity that may have any number of goals including 1) pre-empting niche space away from undesirable plant species and preventing their establishment, 2) creating functional wildlife habitat, 3) increasing faunal biodiversity, 4) returning the plant community to a reference state (but see Monaco et al., 2012), and 5) improving ecosystem function (Ehrenfeld, 2000), including re-establishment of agricultural productivity. Because secondary invasion often occurs within restorations (Mulhouse and Galatowitsch, 2003; Zedler and Callaway, 1999; but see Rinella et al., 2012), it is unclear whether revegetation within restoration is effective for pre-empting niche space away from weeds. Most revegetation/restoration research lacks non-revegetated controls that illustrate how revegetation affects secondary invasion compared to the effects of executing other weed management techniques. Our research addresses this gap.

Riparian areas in the Northern Great Plains are in a state of constant flux: new habitats are created through disturbance (flooding, ice scouring) that transforms old habitats. Succession transitions from cottonwood and willow seedlings, to sapling thickets, to cottonwood forest, to shrubland, then to grassland. This successional trajectory results in non-linear changes in above-ground biomass production and soil abiotic properties (Boggs and Weaver, 1994). Much like the disturbance of flooding or ice scouring, noxious weed removal opens up space for establishment of undesirable species. This vacant niche may be exploited by native species or non-native species, depending on propagule availability and environmental factors that allow recruitment and establishment (Corenblit et al., 2007; Gabler and Siemann, 2012; Srivastava and Vellend, 2005). Depending upon the scale of invasion, removing Russian olive trees can create a high level of disturbance by removing a large amount of plant biomass and canopy cover (Figure 1), which effectively creates a new set point for plant succession to begin.

When invasive species alter ecosystems, post-removal restoration may be particularly important (Gordon, 1998). In the case of invasive plant removal, revegetation is often the default restoration approach. Implicit within the revegetation approach is the theory that establishing a plant community passively brings both above-ground and below-ground fauna to the site (Hobbs and Cramer, 2008). Restoration of forests and grasslands are often studied to determine factors influencing their success, yet riparian restorations are rarely examined from this perspective (Ruiz Jaen and Aide, 2005).

In this paper, we report plant understory composition prior to Russian olive tree removal, and then yearly for two years after removal. We compare the plant communities of four restoration treatments as well as established control plots where no restoration was conducted and report the costs of removal, subsequent control, and revegetation. We test two specific hypotheses: 1) revegetation prevents secondary invasion, and 2) revegetation is necessary to establish desirable plant species after Russian olive removal.

MATERIALS AND METHODS

This study was conducted at the 22,500 ha USDA-ARS Fort Keogh Livestock and Range Research Laboratory located near Miles City, MT. The research laboratory is within the mixed grass prairie of the Northern Great Plains with an average elevation of 780 m. Native vegetation is predominately grama-needlegrass-wheatgrass (*Bouteloua-Stipa-Agropyron*) mix (Kuchler 1964) with less abundant small shrubs including silver sage (*Artemisia cana* Pursh *ssp. cana*), big sage (*Artemisia tridentata* Nutt.), winter fat (*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit, formerly *Ceratoides lanata*), and small trees such as

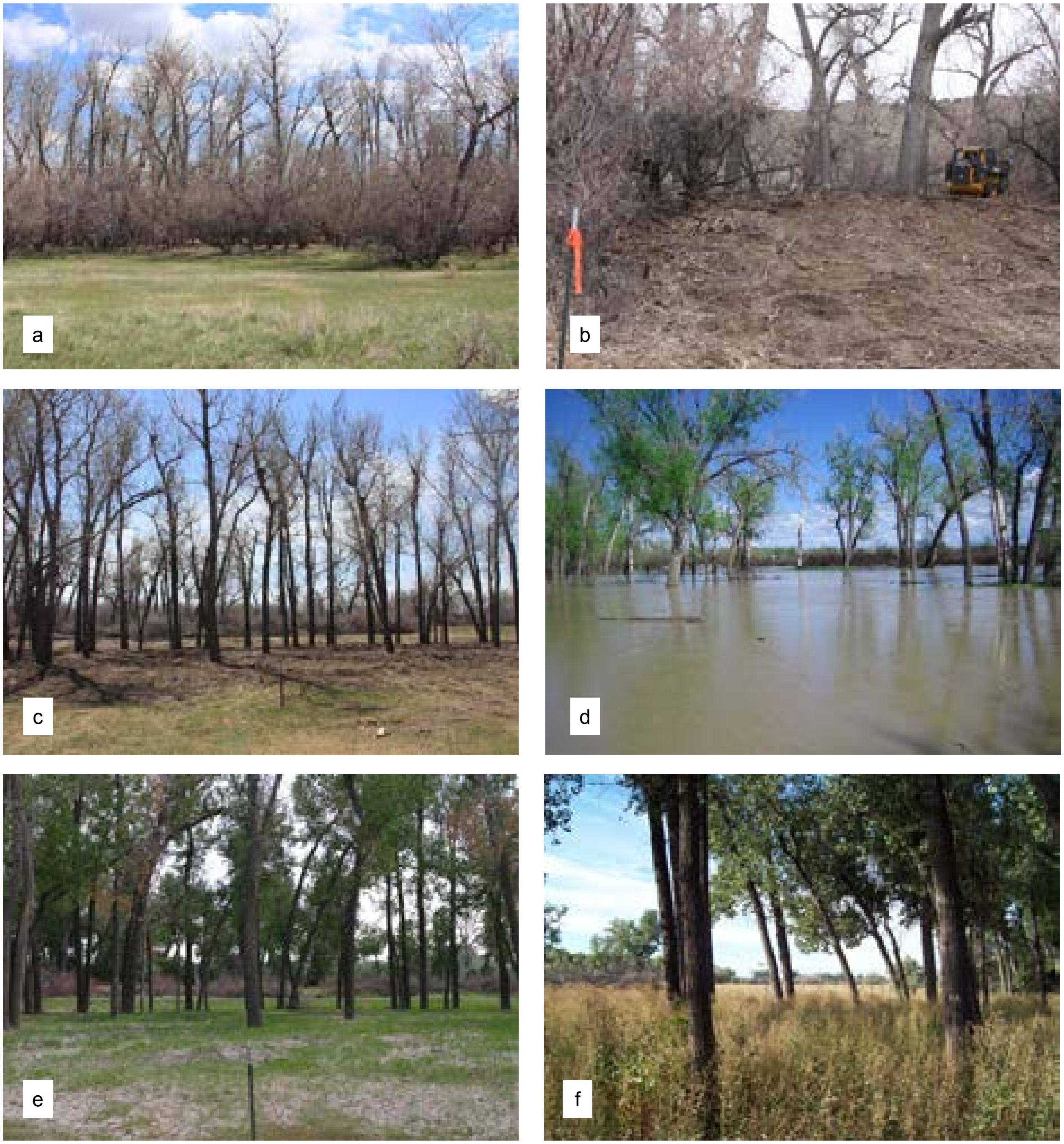

Figure 1. Photos before, during, and after removal. Photos a and c through f show Block 1 through time. Photo b shows what Block 4 looked like during the removal process. a) April 2010, pre-removal; b) April 2011, during removal; c) April 2011, post-removal; d)May 2011, during flood; e)April 2012, pre-restoration; f) June 2013, post-restoration. Photo (e) shows abundant cottonwood seedling recruitment after the flood, and (f) indicates that some of these seedlings survived through the following year.

juniper (*Juniperus communis* L.). Average annual precipitation is 340 mm with 60% received from April through September.

Approximately 8 miles of the Yellowstone River flows through Fort Keogh. Four replicate 0.5 ha blocks were established adjacent to the Yellowstone River on a Glendive fine sandy loam soil. All blocks were completely removed of Russian olive trees in April and May of 2011 using a John Deere 326D skid steer with a tree shear attachment (Grace Manufacturing). The cut stumps were immediately sprayed with a 1:3 mixture of Element 4 (triclopyr) and blue basal bark oil. The cost per hectare of removing these 2500 trees (excluding equipment costs) was 17.7 person hours, 39.5 liters of fuel, $427 in herbicide costs (7.9 liters of triclopyr per ha). Figure 2 shows removal area. The resprouts and Russian olive seedlings were sprayed with 1 oz. Element 4, 3 tsp. Milestone (aminopyralid), and 1 oz. surfactant mixed in 11.4 liters of water with a backpack sprayer in fall of 2011 and 2012. Spraying was conducted in summer of 2013 in order to include salt cedar. Table 1 shows the number of Russian olive seedlings that herbicide was applied to and the cost per ha of these follow up treatments.

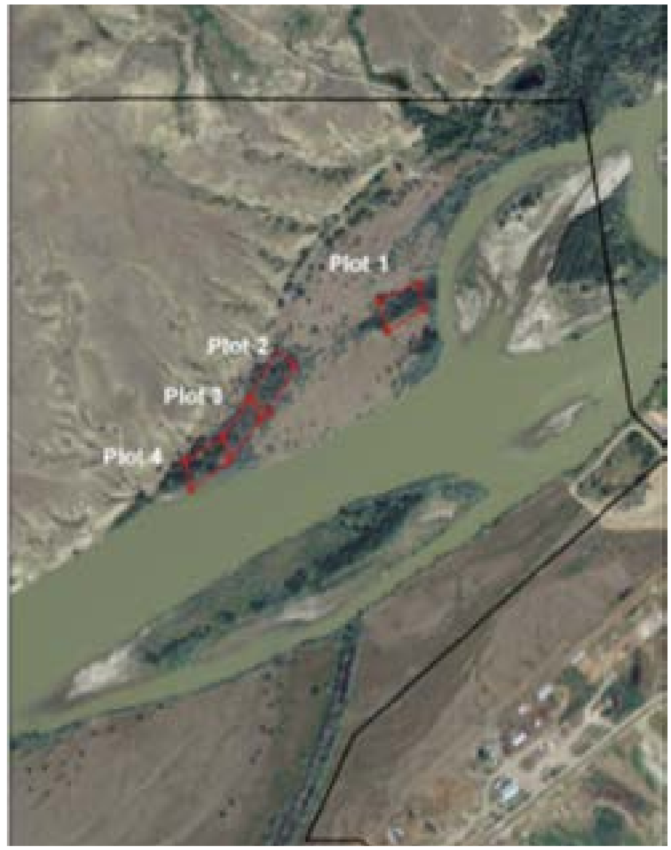

Figure 2. Aerial view of removal plots along the Yellowstone River near Miles City, MT.

Table 1. Follow up Russian olive treatments in cleared areas

year	# treated/ha	total resprouts	total seedlings	person hours/ha	liters of herbicide/ha
2011	8	98	0	0.2	1.4
2012	49	71	515	0.4	8.4
2013	20	no data	238[a]	0.4	3.2

[a] counts of resprouts and seedlings were combined in 2013
[b] Includes spraying approximately 42 saltcedar saplings per acre

Each block was divided equally into 5 treatments; (1) control with no revegetation (2) seeded herbaceous layer only (3) seeded herbaceous layer with shrub plantings (4) seeded herbaceous layer with tree plantings and (5) seeded herbaceous layer with trees and shrubs planted. For the tree and shrub plantings, one- year-old conservation grade woody stock was procured from local sources. Due to flooding in May of 2011, revegetation occurred in April of 2012. Figure 3 shows the temperature and precipitation patterns for Ft. Keogh from the time of Russian olive removal to our final data collection in 2013. All plots except the control plots were sprayed with Roundup (glyphosate) in the fall of 2011 and before woody species planting in spring of 2012. A skid steer and tractor, each equipped with a 20cm auger, were used to excavate planting holes for the trees and shrubs. Each plant received approximately 3.75L of water at

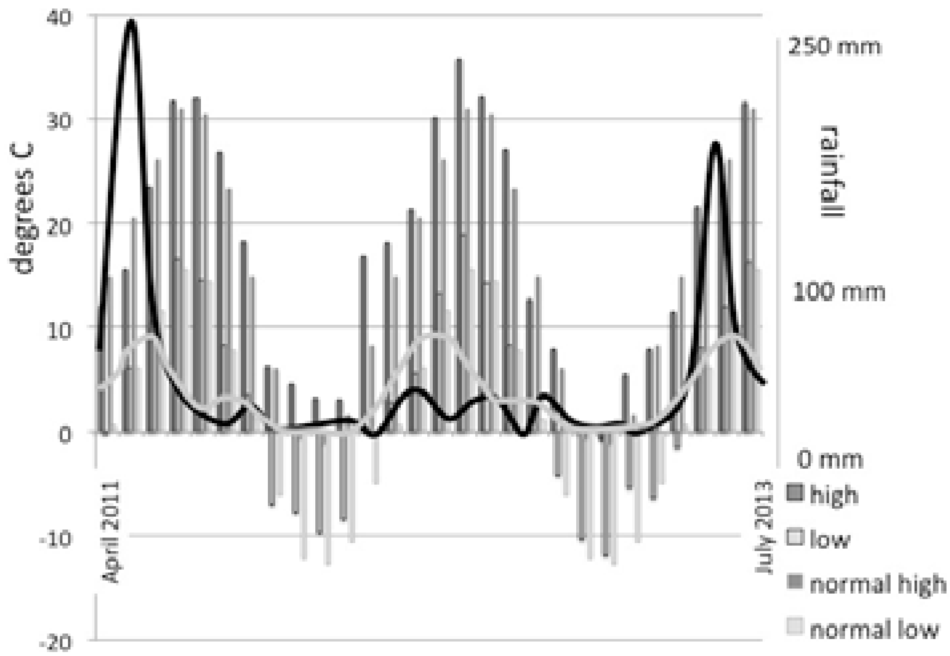

Figure 3. Measured monthly average high and low temperatures (bars) and precipitation amounts (line) during and after Russian olive removal at Ft. Keogh. Non-outlined bars and greyed line indicate normal levels.

planting time only. Weed barrier fabric (0.91m x 0.91m) was placed around 50% of the planted woody species. Woody species planted included narrowleaf cottonwood (*Populus angustifolia* James), plains cottonwood (*Populus deltoides* W. Bartram ex Marshall ssp. *monilifera* (Aiton) Eckenwalder), box elder (*Acer negundo* L.), green ash (*Fraxinus pennsylvanica Marshall)*, golden currant (*Ribes aureum Pursh)*, chokecherry (*Prunus virginiana L.)*, buffaloberry (*Shepherdia argentea (Pursh) Nutt.)* and Woods' rose (*Rosa woodsii Lindl.)*.   Herbaceous species seeded were: slender wheatgrass (*Elymus trachycaulus (Link) Gould ex Shinners), western wheatgrass (Pseudoroegneria spicata (Pursh) Á. Löve), Prairie cordgrass (Spartina pectinata Bosc ex Link), switchgrass (Panicum virgatum L.), common yarrow (Achillea millefolium L.), prairie coneflower (Ratibida columnifera (Nutt.) Wood & Standl.), American vetch (Vicia americana Muhl. ex Willd.), Canadian milkvetch (Astragalus canadensis L.), white prairie clover (Dalea candida Michx. ex Willd.), purple prairie clover (Dalea purpurea Vent.), Maximillian sunflower (Helianthus maximiliani Schrad), blue flax (Linum perenne L.), Rocky Mountain bee plant (Cleome serrulata Pursh.), and Rocky Mountain penstemon (Penstemon strictus Benth.).* We derived this species list from NRCS (2008) and the total application of all seed was 1.2 PLS per hectare. Table 2 shows the cost per hectare of revegetation.

Table 2. Cost per ha of revegetation

	person hours	materials (USD)
Prep spraying	1.6	$6.8 [a]
Harrowing and seeding	0.7	$105
Tree/Shrub transplanting	10 [b]	$111 [c]

[a] 1 liters of glyphosate/ha

[b] this number increases to 15 when weed fabric placement is included

[c] this number does not include the cost of the weed fabric ($83)

Herbaceous seed was broadcast seeded and a harrow and hand rake was used to ensure seed/soil contact. All plots were fenced to USDA-NRCS wildlife fence (NRCS 2006, 2008) specifications to protect the woody plants from wildlife and cattle browsing.

Vegetation cover was assessed by randomly locating six Daubenmire frames (0.1m2) within each of the five plots within each of the four blocks each summer. Plant cover by functional group (native perennial grass, exotic perennial grass, exotic forb, native forb, exotic annual grass) was collected using the point-intercept method (Jonasson 1988). We identified and recorded every herbaceous species growing in every subplot throughout the growing season. We classified all thirteen of our seeded herbaceous layer species as "desirable". "Problem" species were exotic species that can be invasive under certain conditions: annual brome grasses, knapweeds, and salt cedar.

Data analysis:

The statistical software we used was JMP 10.0.2 (SAS Institute, Cary NC). We determined the effect of weed fabric on tree and shrub survival by running a standard least squares model for the effects of species identity, weed fabric presence, and their interaction on percent survivorship. Cover data were analyzed by analyzing the effects of year, restoration (yes or no), and their interaction on the change in 1) problem species cover and 2) native species cover from the previous year using a standard least square model. We did not separate the different restoration treatments as we do not expect trees and shrubs to interact with each other or the herbaceous layer until plants become larger and the restoration matures. Averages presented in the text are ± one standard deviation and are raw cover percentage values rather than the calculated change values. The frequency of desirable species per restoration treatment (yes or no) for 1) 2012 and 2) 2013 were compared using a Dunnett's test with the α level set to 0.05.

RESULTS

Our removal technique resulted in a 4% resprout rate the following year (Table 1). Resprouting continued in the following years, and a flush of new germination of Russian olive in the plots resulted in a 21% regeneration rate (515 out of 2500 trees removed) in 2012 and of 10% in 2013 (Table 1).

Tree and shrub survival from the time of planting in spring of 2012 to the following spring (2013) is shown in Table 3. Green ash had the highest survivorship of the tree species (84.6%), and Woods rose had the highest survivorship of shrub species (92.4%). Narrowleaf cottonwood had relatively poor survivorship at 25%. Weed fabric did not significantly affect survival ($F_{15,90} = 3.23$, $p = 0.67$). Overall survival of all transplants was 64% (±32).

Cover of understory vegetation in our closed-canopy Russian olive stand prior to removal was low: 10% (Table 4). Problem species had 2.1% (±3.0) and native species had 0.8% (±2.2) cover. Understory composition responded dramatically to the removal treatment: native species cover rose to 7% (±3.3) ($F_{1,38} = 6.98$, $p < 0.02$), whereas problem species cover and total species did not change. Total cover values were quite low in 2012 (4.9%, Table 4), probably due to the drought. From the year we planted restoration (2012) to the following year, total cover (Table 4) and total cover of both problem and native species increased significantly ($p < 0.01$), likely due to the higher rainfall in 2013 (Table 4). Cover of problem species increased from 1.7 (±1.8) to 6.1% (± 2.4) and cover of native species increased from 3.0% (±1.9) to 5.5% (±3.3). We detected no differences in problem or native species cover between restored and unrestored plots in 2013 (all $p > 0.14$).

However, the presence of desirable species was higher in restored plots (Figure 4).

Table 3. Percent survivorship of planted tree and shrub species after the first winter.

Species	Percent survival	1 StDev
Narrowleaf cottonwood	25	0.42
Plains cottonwood	50	0.43
Box Elder	50.3	0.33
Green Ash	84.6	0.17
Golden currant	50.5	0.17
Chokecherry	63.1	0.31
Buffaloberry	65.8	0.20
Woods rose	92.4	0.22

Table 4. Total plant cover and growing-season rainfall amounts per year of the study

Year	% total plant cover	standard deviation	April-July rainfall (mm)
2010	10.0	6.2	335
2011	9.9	5.8	420
2012	4.9	3.3	78
2013	19.2	5.5	302

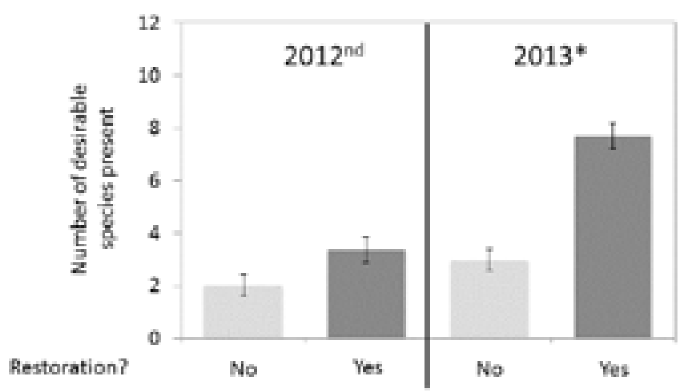

Figure 4. Number of planted herbaceous-layer species emerged in the plots the year of planting (2012) and the following year (2013). The number of planted species was not different between treatments in 2012 (p = 0.19, "nd" on the graph) but the following year was significantly higher in plots where seeding was performed (p = 0.0002, "*" on the graph). Bars are one standard error.

DISCUSSION

In 2012, southeastern MT experienced one of the four driest years on record since 1878 (National Climatic Data Center, Asheville NC), yet tree and shrub survivorship was high and planted herbaceous species persisted (either as seeds or juveniles) and were detected in the following year. Although standard vegetation sampling techniques were not sensitive enough to detect cover of planted species, we did detect an effect of restoration by measuring species presence/absence. Restoration was effective in increasing the number of desirable species in the plots with relatively high tree and shrub survivorship and some establishment of the majority of understory species that we planted. Two desirable species were present in control plots in the years before and after restoration, compared to an average of seven desirable species in planted plots. This supports the use of restoration as a tool to increase species diversity (Srivastava and Vellend, 2005). Our hypothesis that restoration would reduce secondary invasion was not supported, however: problem species abundance did not differ between restored and unrestored plots. While many studies show that restoration can introduce higher levels of problem species (summarized in Robichaud et al., 2000), we did not see lower levels in our control plots, probably because they experienced a very high level of disturbance similar to our restored plots.

Our method of Russian olive removal resulted in an extremely high level of soil disturbance (Figure 1b and c). It is likely because of the high level of soil disturbance and very low cover in 2012 that the presence of weed fabric did not increase tree and shrub survivorship: any established competitors for water and light were very small. Thus the recommendation for using weed fabric (NRCS, 2006) was over-conservative in the short-term, although weed fabric may allow for greater growth rates and long-term survival in surviving trees and shrubs: this will be measured in upcoming years. Conducting Russian olive removal using a non-mechanical technique resulting in less soil disturbance (for example, a chainsaw) would likely result in very different restoration outcomes.

Our removal technique in combination with the 50-year flood the site experienced just after removal (Figure 1d) likely strongly affected both Russian olive resprout rates and the composition of the understory vegetation. Higher total plant cover in 2011 post-removal compared to 2012 may have been due to the high water availability and colonization of the site from the flooding. Our reported 4% resprout rate includes those trees that resprouted from tree roots that were exposed by the flooding. If we were only to report stump resprouts, this percentage decreases to 0.4%. However, our regeneration rates of 21% in 2012 and 10% in 2013 that include new seedlings illustrate the importance of inspection and periodic control of this invasive species. Because Russian olive trees do not become reliably reproductive until they reach ten years of age (Lesica and Miles, 1999), it is possible to control these nascent reinvasions by conducting re-entry kills less frequently than once per year, although herbicide applications are not always effective agents of mortality, and less so when trees are larger. In addition, spraying larger trees has a greater likelihood of damaging adjacent, desirable vegetation.

We chose to evaluate our treatments based on set objectives of 1) native and desirable plant species abundance and cover and 2) resistance to secondary invasion. Because of intensive agricultural use of riparian areas and the non-equilibrium dynamics already in operation in this system, restoration with the goal of matching conditions to intact reference sites is likely untenable (Monaco et al., 2012; Richardson et al., 2007; Zedler & Callaway 1999). In this case, tree removal followed by drought resulted in an extreme reduction in existing understory. Resprouting is common after removal (Stannard et al., 2002) and appears to occur without regard to climate and independent of interactions with other plants (Figure 5). Therefore, untreated Russian olive resprouts may have a competitive advantage over both secondary invasive species and desirable natives. In order to prevent Russian olive resprouts from competing with desirable vegetation, we recommend early re-entry kills. In our case with the substantial soil surface disturbance applied by our removal technique, both secondary invasive species and desirable natives must establish from seed, and their ability to do so is largely driven by climatic factors (Figure 5). Plants generally do not affect each other's growth until they are large enough to influence resource acquisition (i.e. light, water, nutrients) of neighboring plants (as in Weiner et al., 2001). Our experimental time frame of two years post-restoration was not long enough to observe competitive dynamics, niche pre-emption away from secondary invasive species, or plant community function. Restoration can be successful at reducing the densities of undesirable species in the long term (Rinella et al., 2012). We hope that by continuing to track these plots, we can compare the function of our restored plant community with multiple analogues: intact cottonwood stands and a gradient of Russian olive population densities, however to do so now would be premature.

CONCLUSIONS

Restoration can improve sites that have been degraded by weed invasion. Our total plant cover by the end of this study was almost twice that found prior to Russian olive removal indicating that we had an increase in herbaceous forage, likely as a result of tree removal. We found that restoration plantings increased the number of desirable species at a site, but establishment rates and growth were slow and did not show a signal in terms of differential levels of desirable species cover between restored plots and unrestored controls. This indicates that particularly in semi-arid systems such as are found in southeastern Montana, auxiliary benefits of restoration on vegetation characteristics and ecosystem function (such as invasion resistance) may take many years to develop, even when restoration plantings successfully establish.

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Observations on the Biological Control of Dalmatian Toadflax in Oregon

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ABSTRACT

Dalmatian toadflax (*Linaria dalmatica*) has become a prolific invasive plant of rangelands in the State of Oregon since its arrival in the early 20th century. Dalmatian toadflax impacts an estimated 141,640 hectares (350,000 acres) primarily in the high desert ecosystem east of the Cascade Mountain range. In 2001, a classical biocontrol program using the stem-boring weevil *Mecinus janthiniformis* was implemented to reduce densities of Dalmatian toadflax and improve ecological integrity. In our post-hoc observational study, we found that *M. janthiniformis* had become widely established on toadflax infestations independently of human dispersal, and the weevil had reduced toadflax density since the original releases. We used historical biological release and monitoring data, and conducted a limited statewide survey of Dalmatian toadflax and *M. janthiniformis* in 2013. The results showed that *M. janthiniformis* has reduced estimated Dalmatian toadflax densities at former release sites from an average of $9.45 \pm 1.34/m^2$ to $5.5 \pm 1.1/m^2$. Across release sites, there was an average 50%, and maximum 98% reduction in plant density. The weevil has naturally migrated beyond the original release sites with the median distance from release at 1.5 kilometers and maximum of 60 km over a 13 year period. Results from a sentinel site showed that toadflax rebounded following 90% control; however the weevil was able to track and re-suppress the resurging outbreak. Our results indicate that the biocontrol of Dalmatian toadflax is an emerging regional success and that redistribution of the weevil is no longer necessary.

Nomenclature: Dalmatian toadflax, *Linaria dalmatica*, *Mecinus janthiniformis.*
Keywords: Dalmatian toadflax, *Linaria dalmatica*, *Mecinus janthiniformis*, stem boring weevil, classical biological control, insect dispersal.

INTRODUCUTION

Monitoring biological control projects at the regional level provides both challenges and opportunities in determining their general efficacy (Van Hezewijk et al., 2010; Weed and Schwarzländer, 2014). Descriptions of efficacy become more subjective with the transition from local to a larger scale; in this case, the state level. Large-scale monitoring combined with intensive site research can be mutually beneficial for ecologists and those tasked with region-wide implementation of control measures across landscapes with multiple land-use and disturbance regimes (McEvoy et al., 1991). The implementation of significant monitoring protocols contributes to the understanding of "success" in classic biological control projects (McEvoy et al., 1993, Syrett et al., 2000). This project is indicative of the practicality of citizen science for substantial data volume collection over large spatial and temporal extents (Bonney and Dickinson, 2012). Here, we report on the biological control of Dalmatian toadflax *Linaria dalmatica* (L.) Mill. (Plantaginaceae) using the stem-mining weevil *Mecinus janthiniformis* Tosevski and Caldera (Coleoptera: Curculionidae) in the state of Oregon. The Oregon Department of Agriculture (ODA) has conducted statewide biological control assessments on tansy ragwort *Senecio jacobaea* L. (*Asteraceae*) (Coombs et al., 1996), and Mediterranean sage *Salvia aethiopis* L. (*Lamiaceae*) (Coombs et al., 2008). Efficacy reviews of national and international classical biological control projects offer a more holistic perspective on the still relatively scarce literature on long-term agent-host interactions (Hoffman and Moran, 1998; Huffaker et al., 1959; Syrett et al., 2000). These case studies provided evidence of the lasting nature of biological control projects, and indicate that success occurs on the order of decades.

Dalmatian toadflax is an erect, short-lived perennial herb that is native from southeastern Europe through southwestern Asia. In both the United States and Canada, Dalmatian toadflax has exhibited a strong proclivity for weediness that has resulted in it being listed as a noxious weed or weed seed in three Canadian provinces and in 12 U.S. states (Sing and Peterson, 2011). This hardy, glabrous plant has a vigorous reproductive cycle both vegetatively and by seed (Alex, 1962). Dalmatian toadflax's ability to outcompete native vegetation impacts forage plants for livestock and reduces endemic plant species densities (Jeanneret and Schröeder, 1992; Lajeunesse, 1999). The sheer density of healthy, established Dalmatian toadflax populations can deter cattle from grazing infested areas as well (Jeanneret and Schröeder, 1992; Lajeunesse, 1999).

In 1983, ODA began releasing biological control agents to control Dalmatian toadflax populations across Oregon (Coombs, 2013). Releases of the defoliating moth *Calophasia lunula* (H.) (Lepidoptera: Noctuidae) occurred in 1983, while the root gall weevil *Gymnetron linariae* (P.) (Coleoptera: Curculionidae) and the stem boring weevil *M. janthiniformis* were introduced in 2001. *M. janthiniformis* has become the only classical biological control agent to be widely established.

Beginning with seven releases of *M. janthiniformis*, the program expanded to the maximum annual number of releases reaching 57 in 2007, and subsequently trending downward to the minimum annual number of releases of two in 2011. A total of 219 reported releases were made, distributing 71,119 total weevils in Oregon between 2001 and 2012. Nineteen out of the 36 counties in Oregon had *M. janthiniformis* released within their boundaries, which targeted all of the known major infestations across the state. The year 2009 witnessed the largest number of weevils released with 25,950 weevils released across Oregon.

The original releases of *M. janthiniformis* were conducted in seven Oregon counties; in addition the weevil had already become established in Idaho by this time (Andreas et al., 2013; Coombs, 2013). In 2002, the weevil was recovered in two of the original seven counties, Gilliam and Wallowa. Several of the release populations became collectible as nursery sites in 2004, and were redistributed to other infestations. Reductions in stand densities of Dalmatian toadflax were noted by 2006 across Oregon, Washington and Idaho (Coombs, 2013). Releases of *M. janthiniformis* continued at major infestations of Dalmatian toadflax in 2007 by partnering with the Bureau of Land Management, United States Forest Service, and county weed programs, because of emerging success witnessed in parts of Oregon. Collections and releases of *M. janthiniformis* continued in higher numbers through 2008 and 2009 throughout central and eastern Oregon (Coombs, 2013). In 2010, *M. janthiniformis* was spreading independently of human releases in Harney County (P. Rasmussen, personal communication, November 3, 2013). In 2011, collection and redistribution by ODA of *M. janthiniformis* was turned over to the county weed control programs to finish the implementation of the project (Coombs, 2013).

This study assesses the impact and distribution of *M. janthiniformis* on Dalmatian toadflax populations over the past 13 years. This post-hoc observational study addressed three questions: [1] Has *M. janthiniformis* had any impact in reducing densities of Dalmatian toadflax in Oregon since inception of agent release; [2] Is *M. janthiniformis* spreading naturally to new sites; and [3] Should ODA still facilitate spread of the agent? In order to address these issues, historical release and survey data collected by ODA entomologists and agronomists, United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS), county, and local government services was analyzed. A 2013 statewide survey of release sites was used to compare against original release records to determine relative efficacy of *M. janthiniformis*.

MATERIALS AND METHODS

2.1 Description of the study area

Our survey was conducted east of the Cascade Mountain range in Oregon where Dalmatian toadflax infestations were reported, ranging from 123° to 116° W, and 41.9° to 45.9° N. Drier conditions paired with well-drained and coarse-textured soils, create habitats where Dalmatian toadflax infestations flourish (Wilson et al., 2005; Robocker, 1974). The study primarily occurred in sagebrush steppe habitat of Northeast and Southeast Oregon.

2.2 WeedMapper Dataset

The ODA Plant Division Plant Division maintains a weed database (WeedMapper) that contains information on the locations of reported weed infestations throughout the state (ODA, 2011). This database includes weed locations from the United States Forest Service, Bureau of Land Management, Soil and Watershed Conservation Districts, Cooperative Weed Management Areas, County Weed Boards, and Oregon State University amongst other cooperators. Geospatial data that comprises the WeedMapper dataset for Dalmatian toadflax began to be collected in 2000. The dataset has 4,891 entries from eight different managing agencies ranging from the local to federal level. This data can be accessed at *www.weedmapper.oregon.gov/*.

2.3 Insect Release Data

Beginning in 2001, releases of *M. janthiniformis* on Dalmatian toadflax populations were recorded using ODA's Biological Control Agent Release form. There were 219 recorded releases reported since the start of the program, detailing the number of weevils released in addition to data pertaining to Dalmatian toadflax, locational, and site status data. Data from the form used in this analysis included: release year, county, latitude, longitude, number of agents released, terrain, vegetation type, land use, disturbance type, infestation type, gross acres of target weed, density per square meter of invasive plant. This data provides a unique wealth of information about infestations of Dalmatian toadflax, and their environment at the time of release of *M. janthiniformis*. We visited release sites while other regional ODA staff provided the other site densities for the analysis in this study.

2.4 Biological Control Monitoring Forms

ODA utilizes a standardized monitoring form when monitoring all of its biological control agents. Data collected by multiple observers at monitoring sites included: date, weed species, agent species, county, latitude, longitude, manager, area, agent stage, agent abundance, invasive plant infested percentage, gross area infested, density of invasive plant/m^2, and notes. Agent abundance estimates for *M. janthiniformis* populations was recorded in observable adults per minute of inspection search time. Infested percentage of invasive plant indicates an estimate of how many plants across the site were attacked by *M. janthiniformis* or bore impacts from their presence such as oviposition scars or feeding damage. Gross area infested indicates an ocular estimate of the observable area that is infested by Dalmatian toadflax. Density of invasive plant indicates the range of densities across the observable site, and an average across the site again using ocular estimates. These observational values are used as a baseline determination for estimating the decline and extent of each toadflax infestation, and contain variation based on multiple observers.

2.5 Long-term Study Site
The Dufur, Oregon, release site at 45.4002° N and 121.2694° W, was monitored over a 13 year period for abundance of *M. janthiniformis* , average density/m^2 of Dalmatian toadflax, and percentage of toadflax infested by the weevil. This site was visited on a regular basis post-release of *M. janthiniformis* in order to estimate weevil and Dalmatian toadflax populations. This site was not set up as an experimental design prior to the release of the *M. janthiniformis*, but was used to estimate annual changes of both weevil and Dalmatian toadflax populations. ODA used this methodology for data collection because of the limited personnel and fiscal resources that could be applied to any individual site, but preferred to use rapid site assessments to allow for broad analysis over a large area and time. The Dufur site was one of the original release sites in 2001, but the release failed because the host plants had been mowed by the landowner in 2002. An additional release of 500 *M. janthiniformis* was made in 2003 and subsequently established. Observations were not recorded in 2005 and 2012.

2.6 Survey Site Selection
The large geographical area and relatively small timeframe for adult *M. janthiniformis* surveys in the late spring of 2013 necessitated a randomized linear feature survey. Linear feature surveys utilize easily accessible thoroughfares such as roads and Off Highway Vehicles (OHV) trails in order to reach as many sites as possible across large areas to achieve the most amounts of data as possible within a limited time. Major watersheds with large Dalmatian toadflax infestations were used as natural isolates within the geospatial distribution of Dalmatian toadflax populations. The major watersheds used as part of this survey were part of the 221 subregion hydrologic units titled Hydrologic Unite Code (HUC) 6 that include areas that are drained by a major river system, groups of streams forming a coastal drainage area, a closed basin, or a reach of a river and its tributaries (Seaber et al., 1987). The linear features were randomized internally within these basin wide HUC 6 watersheds which included: Middle Columbia, John Day, Deschutes, Oregon Closed Basin, Klamath, and Upper Sacramento.

In each of these watersheds, linear features that were in close proximity to WeedMapper or biological agent release data points were identified, digitized, and randomized for survey. These data points were then exported to spreadsheets that were used in conjunction with a GPS to locate sites in the field. In addition to WeedMapper and former biological agent release sites visited, any Dalmatian toadflax populations found randomly along the linear feature being surveyed were also recorded on the monitoring form. Timing of the survey was dictated by the phenology of both Dalmatian toadflax and the weevil. A 10-50% flowering bloom by the toadflax was preferred at the time of the survey for visual identification and locating, while also coinciding with adult *M. janthiniformis* being active and while ovipositing. It was also important to survey while damage by the weevil on toadflax was evident. The time that best fit these desired phenological characteristics was late June into late July. The 2013 survey was conducted between June 17th, 2013 and July, 17th 2013. In the course of three weeks of survey, 54 sites were visited, all within six watersheds.

2.7 Data Analysis

The 2013 survey of weevil abundance and distance from release sites data was analyzed to determine whether *M. janthiniformis* was expanding its range independently of human facilitation. Distance from release was sites was determined using a straight-line distance calculation in ArcGIS, and was generated by using known historical release record sites proximity to WeedMapper and random sites visited in the 2013 survey. We hypothesized that *M. janthiniformis* had spread throughout the range of Dalmatian toadflax infestations in Oregon. If so, there should not be a correlation between distance from release sites and abundance of weevils. Alternatively, if there is a negative correlation; then distance from original release sites would be a limiting factor in weevil abundance. The abundance of weevils was log-transformed prior to analysis to reduce impacts of outliers within the dataset. A linear model was used to test the hypothesis.

A linear model was also used to test whether there was a correlation between weevil abundance and density of Dalmatian toadflax, with host density being the limiting factor for weevils. The abundance data was log transformed prior to running the linear model. Of the 54 sites surveyed in 2013, WeedMapper and Random sites were analyzed for a relationship between distance from nearest release site and abundance of *M. janthiniformis* (n = 33). One of these sites was removed from analysis as it was in a right-of-way zone which had been recently treated with herbicides and mowed, thus removing the weevil. The 20 release sites were excluded because we elected to focus on untreated sites for dispersal analysis.

Two analyses were used in order to assess whether *M. janthiniformis* had any impact on Dalmatian toadflax densities in Oregon: (1) Densities of toadflax prior to release (n = 20 sites) were compared to densities after releases using a one tailed t-test, and (2) densities of toadflax relative to initial release year (year = 0) were compared against years from release using the Kruskal-Wallis non-parametric test, with inter-year determination of significance after adjustment of p-values using the Bonferroni method (Ramsey and Schafer, 2002).

Data analysis of release forms consisted of comparisons between different environmental and

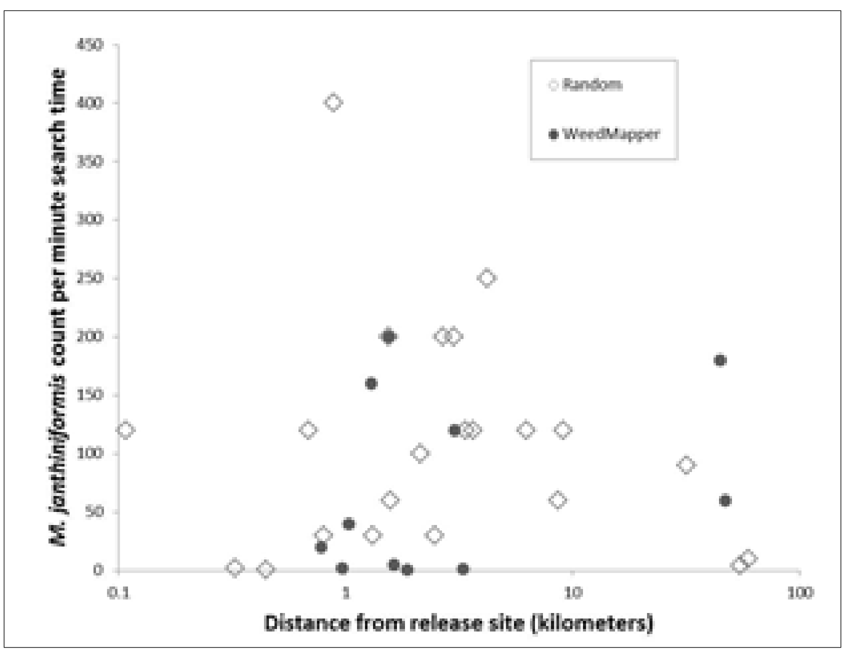

Figure 1. Relationship between abundance of *M. janthiniformis* and distance from nearest release site. Release sites included in figure are non-zero because observations may have not been in the geographic center of the infestation. WeedMapper points found using ODA's WeedMapper database. Random points found throughout statewide survey area.

disturbance types against estimated Dalmatian toadflax densities. A Kruskal-Wallis non-parametric test was utilized to determine significance between different categorical variables, and the Bonferroni method was used to determine inter-categorical significant differences.

2.8 Uncertainty and Error

Fifty-four sites were found to have Dalmatian toadflax and *M. janthiniformis* populations present. Biological agent release and monitoring records were filled out by different observers with varying levels of ecological expertise. Toadflax densities throughout this study were made as estimations of total site density in order to capture site trends. Ocular estimates for site density per square meter of Dalmatian toadflax were conducted by numerous cooperators thereby generating variability between observations. Release forms contained ranges of Dalmatian toadflax densities that that were designed to encourage persons conducting releases to easily indicate site densities (this was a response to low quantity rates of filling out site densities on release forms). When the person conducting releases did not write an integer down for an average, but instead indicated a range, the median value of that range was used as the average site density of Dalmatian toadflax.

RESULTS

3.1 Weevil Dispersal and Abundance

The most remote site recorded in the 2013 survey was approximately 60 kilometers away from the nearest known release, and the median distance was 1.5 kilometers from the nearest release. Using log transformed weevil abundance data, a linear model showed little correlation between abundance and distance from release site (Fig. 1) ($r = 0.009$, p-value $= 0.41$).

3.2 *M. janthiniformis* Site Occupancy

The 2013 survey revealed that *M. janthiniformis* populations were present on all Dalmatian toadflax infestations regardless of plant density including release sites, and with the exception of the heavily disturbed

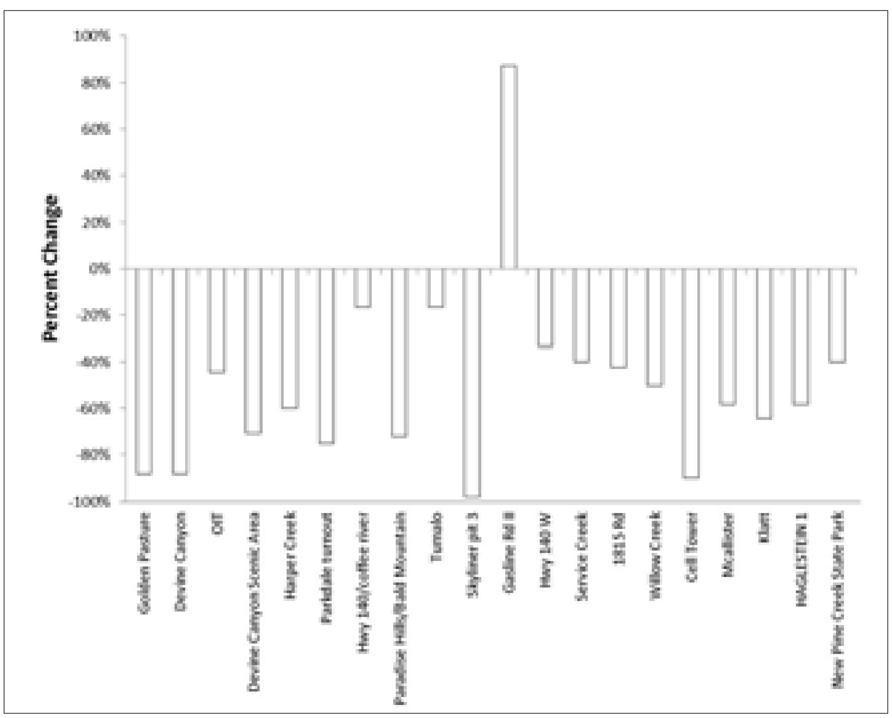

Figure 2. Percent change from release density to 2013 density of Dalmatian toadflax. Mean reduction of Dalmatian toadflax density across all sites was 50%.

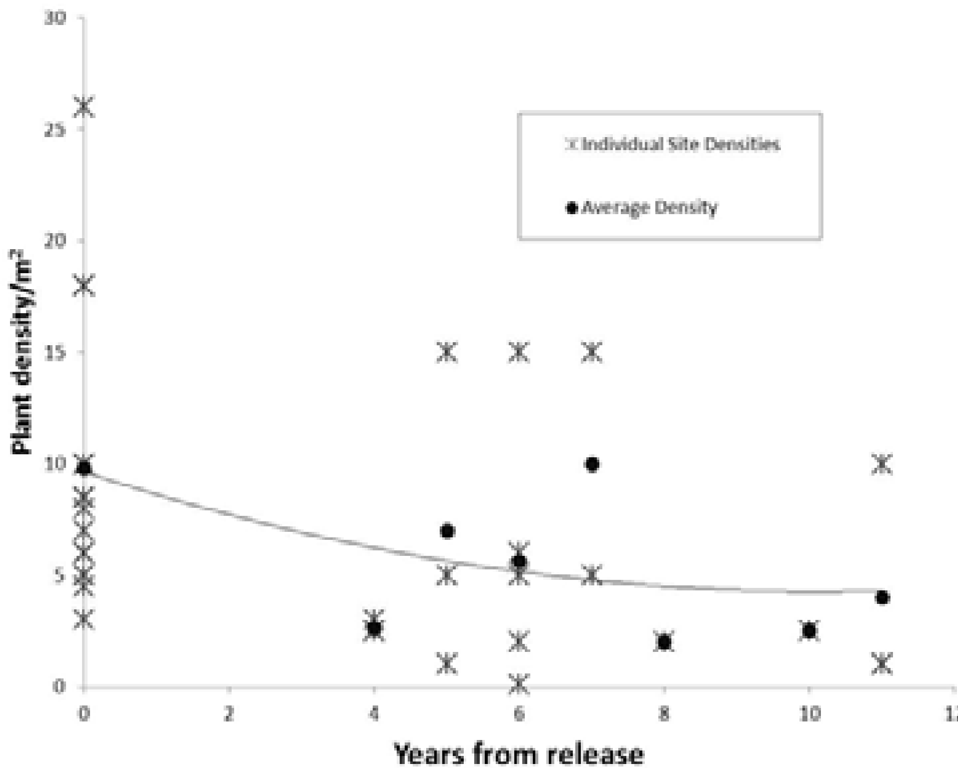

Figure 3. Change in density/m^2 of Dalmatian toadflax relative to release year zero.

site. The average weevil abundance across all sites observed (n = 53) was 90 ± 12. 2 weevils per minute of search time. Using log transformed weevil abundance data, a linear model was used to determine that there was little detectable correlation between abundance and density of Dalmatian toadflax (r = 0.005, p-value = 0.41).

3.3 Plant Population Trends

We found that 95% of release sites monitored in the 2013 survey (n = 20) had declining Dalmatian toadflax densities relative to the original release time density (Fig. 2). The mean reduction of Dalmatian toadflax density across monitored release sites was 50% from time of release.

3.4 Dalmatian Toadflax Density Relative to Release Year

Mean density of Dalmatian toadflax at release sites at the time of release (n = 20) was 9.45 ± 1. 34/m^2, while sites monitored any time after release (n = 20) had an average of 5.5 ± 1.1/m^2. Density of Dalmatian toadflax at sites after release of *M. janthiniformis* were found to be significantly lower than those prior to release (Fig. 3) (one tailed t-test = 1.68, p-value = 0.005). There was no significant difference found between individual years relative to release (Kruskal Wallis, p-value = 0.11).

3.5 Population Trends at Sentinel Site

After an initial failed establishment of *M. janthiniformis* in 2001, the 2003 release successfully established, with a subsequent boom in population in 2004. Prior to establishment of *M. janthiniformis*, the site had an estimated average Dalmatian toadflax density of 8 plants/m^2 (Fig. 4). The rapid expansion of *M. janthiniformis* correlated to a precipitous decline in Dalmatian toadflax densities at the site; to 0.01/m^2 in 2006 (Fig. 4). There was also a pattern present between the percent of plants infested by the weevil, and corresponding estimated average density of Dalmatian toadflax on the site. At low densities, high numbers of weevils per plant can occur from large numbers produced in the prior year.

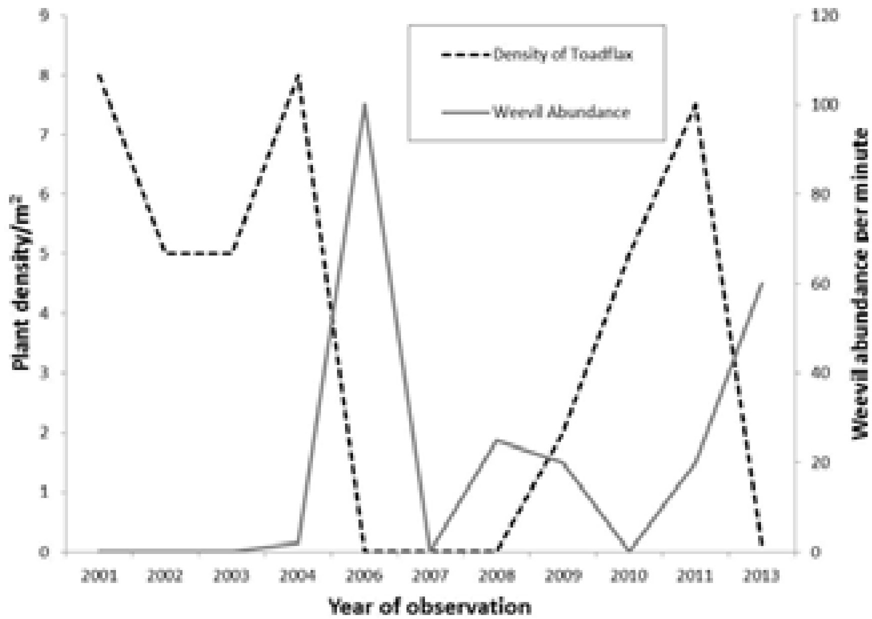

Figure 4. Change in density/m^2 of Dalmatian toadflax relative to abundance of *M. janthiniformis*.

At the Dufur site, establishment of a weevil population that reached high enough levels to reduce the host's density levels was between three and four years, with the decline of toadflax populations occuring after levels of the weevil abundance reached a count of 100 per minute. After establishment of *M. janthiniformis* at Dufur site, the populations of both species begin a classic predator-prey dynamic population state (Abrams, 2000). Although not measured in this study, we observed the resurgence of toadflax densities did not return to the original biomass and, corollarily, propagule production that was observed prior to release of *M. janthiniformis*. Although increasing in density during this time period, the observed plants were stunted and mostly vegetative. These observations were also made at other release sites where reductions in overall site biomass was witnessed.

3.6 Pre-release Data

Data contained in the release forms generated from the launch of the program is illuminating in regards to the relationship between the density of Dalmatian toadflax infestations in relation to geo-physical, land use, and ecological variables. Categories analyzed were terrain, vegetation type, land use, infestation type, and disturbance types relative to the density of Dalmatian toadflax.

3.6.1 Terrain and Dalmatian Toadflax

Foothills were the most common terrain type where *M. janthiniformis* releases were conducted, which represented 43% (n = 94) percent of all the releases (Fig. 5a). The least common terrain type was Foothill – River with less than 1% (n = 1) of releases conducted in these terrain types. The terrain type with the highest average density per square meter of Dalmatian toadflax was mountainous terrain, with an average (n = 15) of 14 ± 2.75/m2 (Fig. 5b). There was significant difference between terrain types (Kruskal-Wallis, p-value < 0.01).

3.6.2 Vegetation Types and Dalmatian Toadflax

Grasslands, shrublands, and a combination of both represented 65% of all vegetation types (n = 149) of which *M. janthiniformis* releases were made on Dalmatian toadflax (Fig. 6a). This vegetation type complex is representative of typical infestations of Dalmatian toadflax east of the Cascade mountain

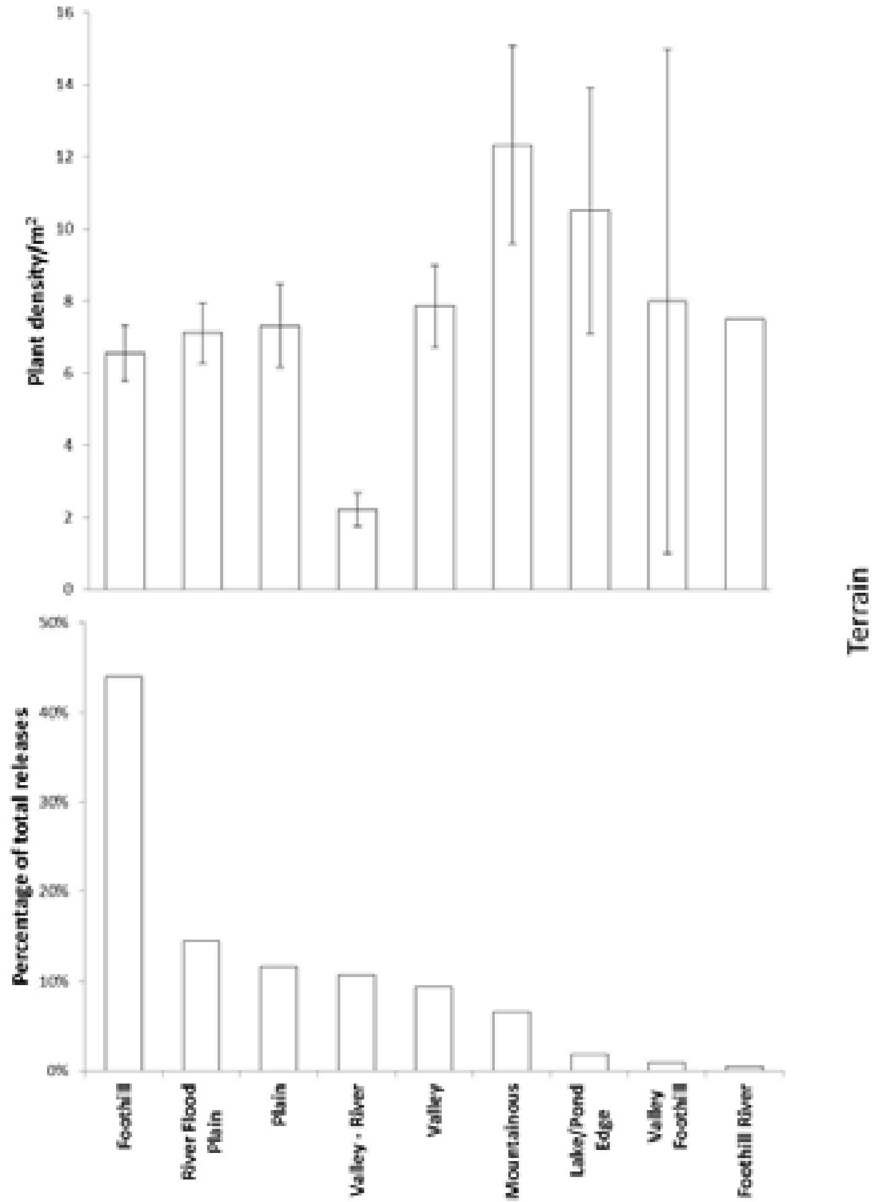

Figure 5 a. Estimated average density of Dalmatian toadflax/m^2 by terrain type and standard error bars. b. Percentage of different terrain types identified *M. janthiniformis* was released (n = 217).

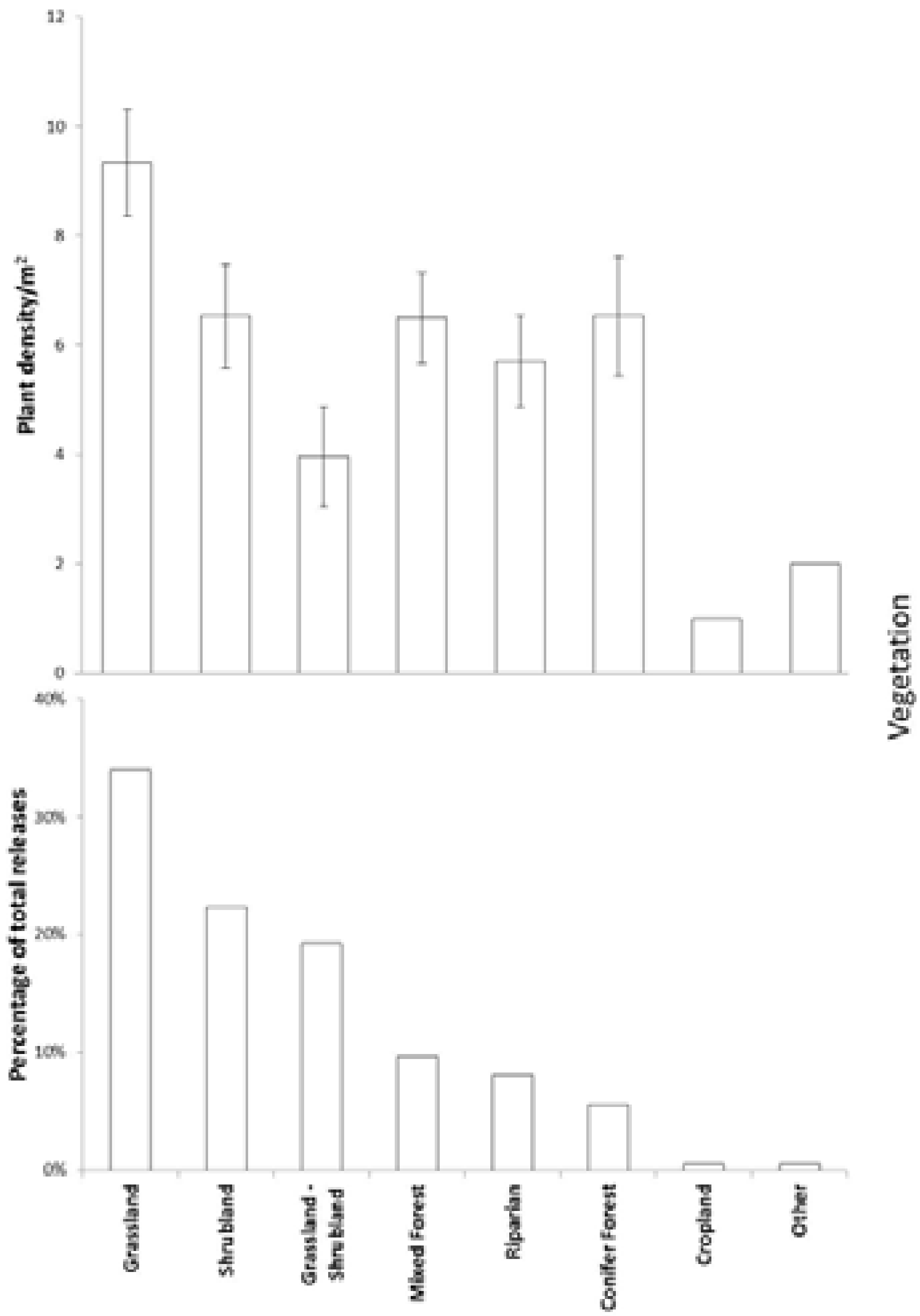

Figure 6 a. (top) Estimated average density of Dalmatian toadflax/m^2 by vegetation type. Standard error bars shown in black. b. (bottom) Percentage of different vegetation types that *M. janthiniformis* was released upon (n = 218).

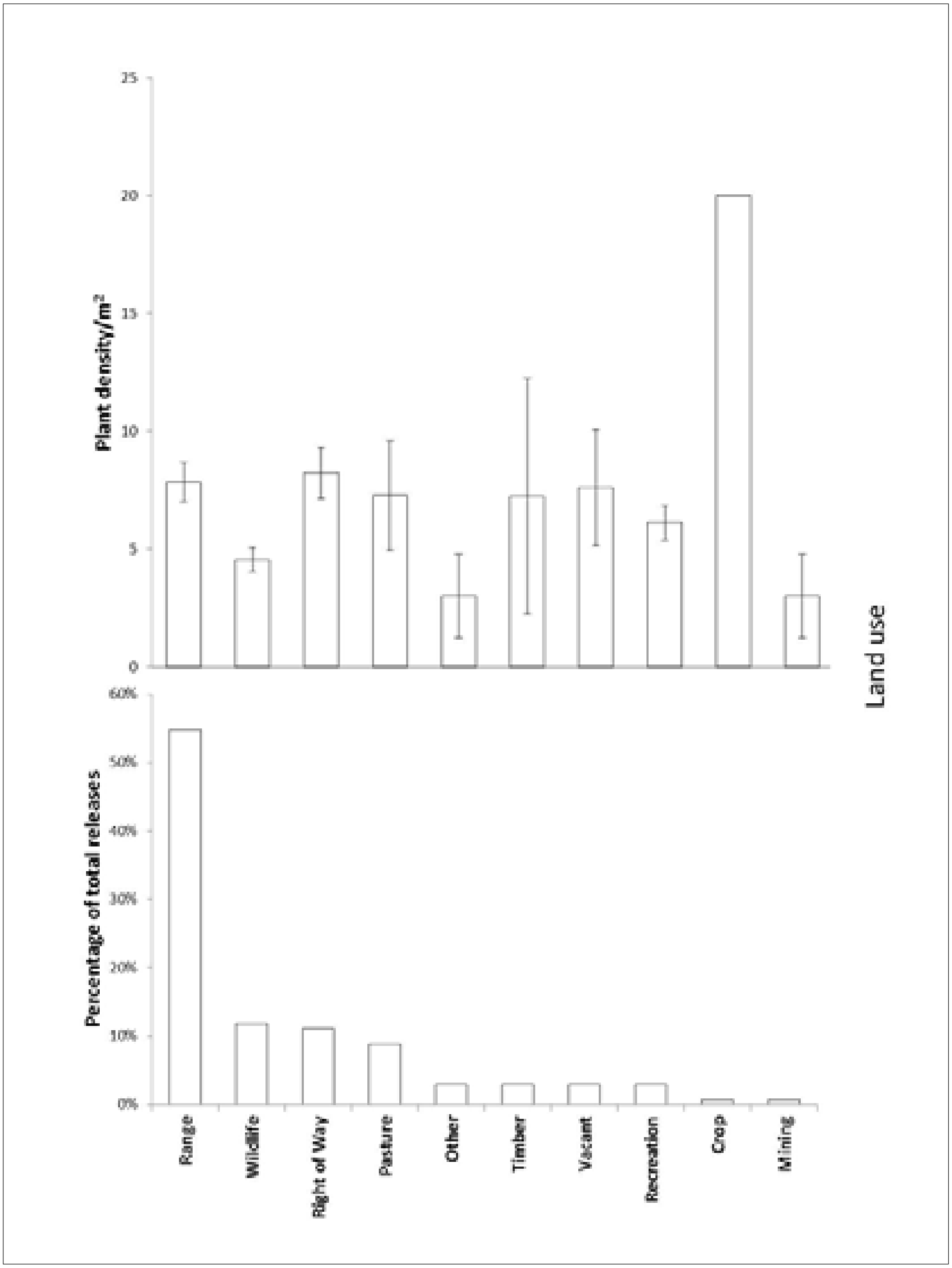

Figure 7 a. (top) Estimated average density of Dalmatian toadflax/m² by land use type. Standard error bars shown in black. b. (bottom) Percentage of land use types where *M. janthiniformis* was released upon (n = 218).

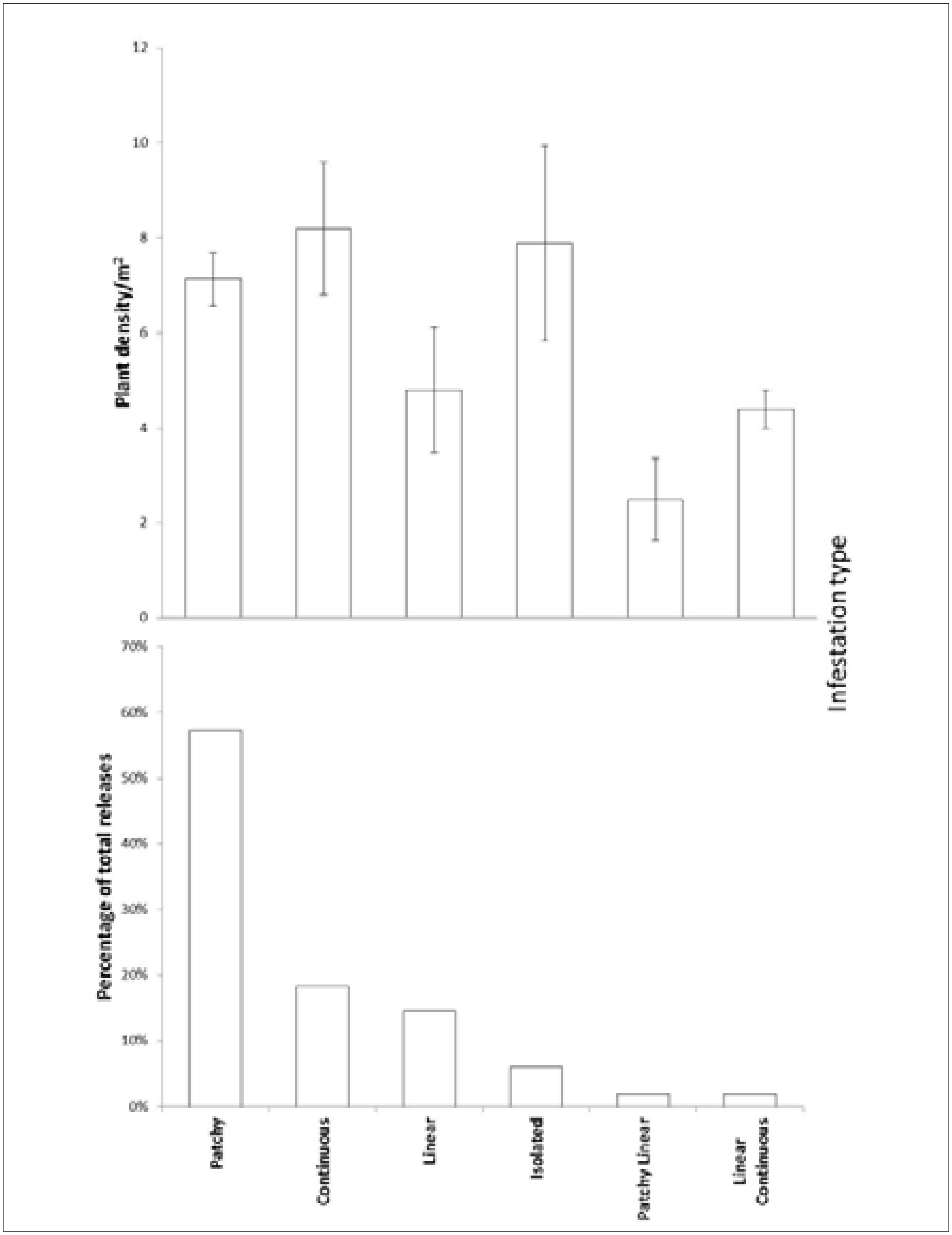

Figure 8 a. (top) Estimated average density of Dalmatian toadflax/m^2 by infestation type. Standard error bars shown in black. b. (bottom) Percentage of infestation types that *M. janthiniformis* was released upon (n = 216).

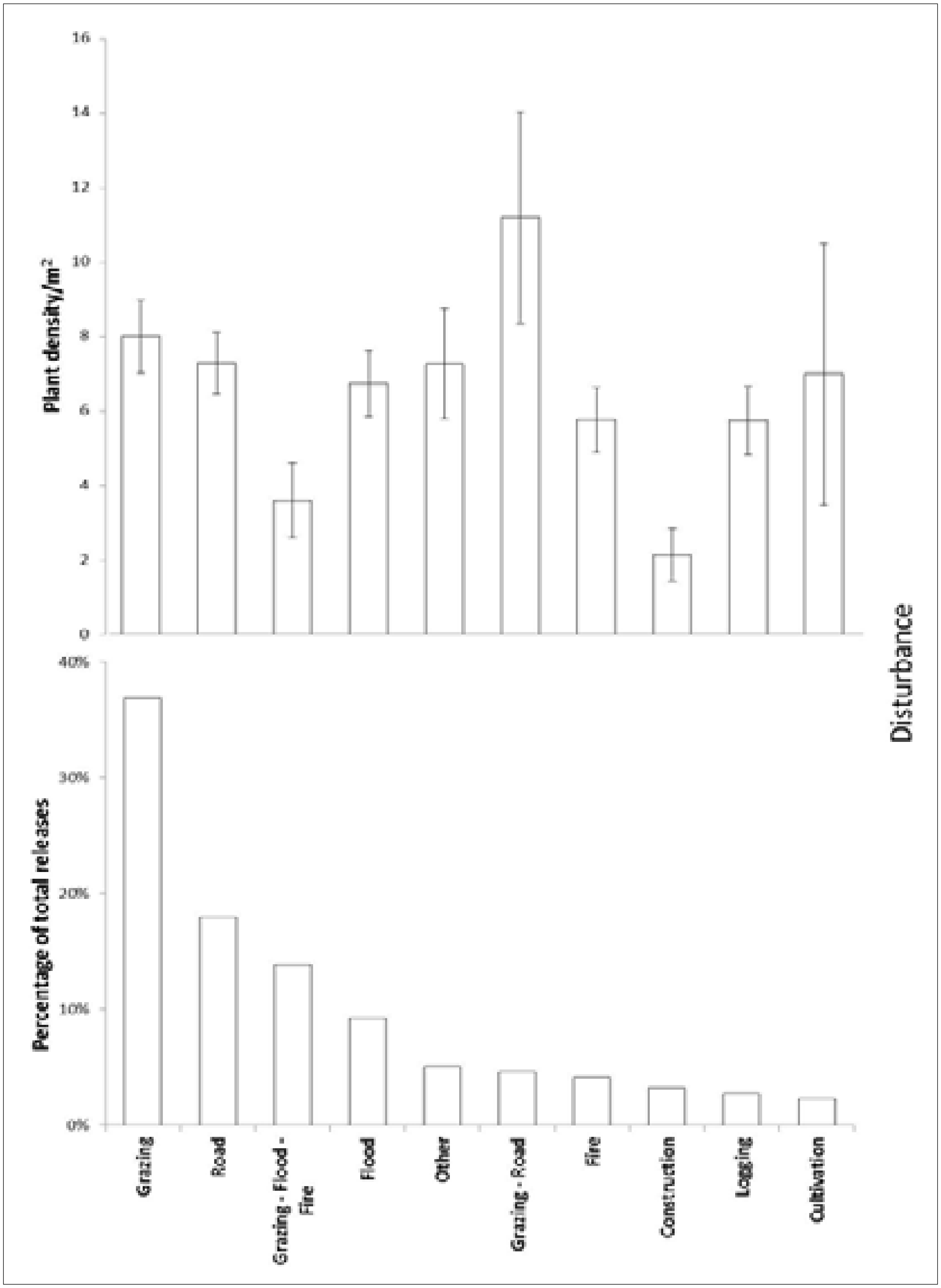

Figure 9a. (top) Estimated average density of Dalmatian toadflax/m² disturbance type. Standard error bars shown in black. b. (bottom) Percentage of disturbance types that *M. janthiniformis* was released upon (n = 217).

range. The vegetation type with the highest average density per square meter of Dalmatian toadflax was also grassland (n = 73), with an average of 9.3 ± 0.97/m2 (Fig. 6b). The relationship between grasslands and the highest density of Dalmatian toadflax may be indicative of toadflax's propensity to outcompete grasses in rangeland environments more effectively than other vegetation types (Robocker, 1974). There was significant difference between density of Dalmatian toadflax infestations in different vegetation types (Kruskal-Wallis, p-value < 0.01).

3.6.3 Land Use and Dalmatian Toadflax

The rangeland land use type (n = 73) represented 54% of all the release sites (Fig. 7a). Rangeland land use type generally correlates to rangeland vegetation types (grassland, shrubland) that Dalmatian toadflax has shown a strong propensity to compete against (Fig. 8). The land use type with the highest average density per square meter of Dalmatian toadflax was abandoned cropland with an average (n = 2) of 20/m2 (Fig. 7b). Because abandoned cropland had only two observations of the same value, no standard error was available. There was significant difference between land use types (Kruskal-Wallis, p-value < 0.01). In abandoned cropland, nearly all competitive native plants were removed from the site allowing for Dalmatian toadflax to proliferate.

3.6.4 Infestation Type and Dalmatian Toadflax

Patchy infestations (n = 123) were the most common infestation type where *M. janthiniformis* releases were made, which represented 57% (Fig. 8a). The least common infestation type was continuous linear with 1.8% (n = 4) of releases. The infestation type with the highest average density per square meter of Dalmatian toadflax were continuous infestations (n = 39), with an average of 8.23 ± 1.3 plants/m2 (Fig. 8b). There was significant difference in plant density between infestation types (Kruskal-Wallis, p-value < 0.01).

3.6.5 Disturbance Regimes and Dalmatian Toadflax

Grazing was the most common disturbance type (n = 80) where *M. janthiniformis* releases were made, which represented 36% of release sites (Fig. 9a). We define disturbance as any perturbation that disrupts the natural plant community structure and function. Disturbances that involved grazing of any kind (n = 120) represented 54% of the total all disturbance types. The least common disturbance type was logging operations with 2% (n = 6) where releases were conducted across the landscape. The disturbance type with the highest average density per square meter of Dalmatian toadflax were grazing and road combinations (n = 10), with an average of 8.9 ± 2.8/m2 (Fig. 9b). There was significant difference between infestation types (Kruskal-Wallis, p-value < 0.01).

DISCUSSION

This retrospective study is an attempt to chronicle the emerging success of the *M. janthiniformis* classical biological control program that was implemented by ODA, APHIS and their partners. There is evidence from the release site comparisons and the long-term observation site that the presence of *M. janthiniformis* on Dalmatian toadflax infestations negatively correlates with plant density (Figs. 2 and 3). There was strong statistical evidence to reject the null hypothesis that densities of Dalmatian toadflax prior to, and after release of *M. janthiniformis* were equivalent (Fig. 3). The 50% observed average net reduction in toadflax densities at release sites over time indicates that a measure of control has been achieved by this classical biological control program. With individual sites having reductions of toadflax density up to 98%, the potential for more robust, overall control is evident. The one site of increasing density was located in a right-of-way where human disturbance may have disrupted the expected downward trends of Dalmatian toadflax impacted by *M. janthiniformis*. Reducing toadflax populations with mechanical or chemical controls reduces weevil numbers by eliminating their food source and oviposition sites for one year, subsequently reducing their population. This initial reduction in toadflax densities should be considered in the context of this study's relatively early analysis of a typical biocontrol program which takes 20-30 years to determine whether the program was successful (Coombs et al., 1996; Coombs et al. 2008).

Because of the observational nature of this study, a regimented and repeated data collection protocol was not available with the exception of the long-term Dufur site. Because of this, only snapshots of the population dynamic between predator-prey relationship were observed (Fig. 4). Expansions and collapses of both species populations are cyclical in time, and appear to generally inversely track each other. The spike in estimated average density that occurred from 2009 to 2011 at the sentiel site is postulated to have significantly less ecological impacts due to the overall reduction in biomass and seed production of the toadflax (Fig. 4). The trend at the Dufur site was similar to reports of precipitious declines documented by multiple cooperators at other sites in Eastern Oregon and in other regions (Van Hezewijk et al., 2010; Weed and Schwarzländer, 2014).

Some of the substantial shifts in population dynamics of the weevil and toadflax are likely affiliated with site-specific variations in a given year, primarily relating to rainfall and density-dependent processes (Weed and Schwarzländer, 2014). If *M. janthiniformis* were having limited or no impact on Dalmatian toadflax densities, one would expect the release sites to have a more equal distribution of increasing and decreasing toadflax densities. Yet 95% of the sites were decreasing relative to their density upon release. This indicates an overall declining trend that could represent an asymptotic trend that is not apparent in the Dufur long-term study site. Although not found to be statistically significant between years, the toadflax density relative to release year shows this potential asymptotic trend. The small p-value observed at year four ($p = 0.07$) relative to year zero should also be considered through a biological interpretation of significance, where non-statistical significance may still contain biological relevance (Martı´nez-Abraı´n, 2008). To confirm whether toadflax densities follow an asymptotic trend following a weevil introduction, data collection across multiple sites with statistically valid replicates would need to be implemented. Any future study on the effect of a biological control agent on its host's overall influence on a given ecosystem should include a metric more ecologically relevant than just density. Utilizing a metric such as the importance value which measures the relative frequency, relative density and relative dominance of a species into a singular value better evaluates the impact of given species on ecosystem more accurately than density alone (Burns and Honkala, 1965).

There was also evidence that *M. janthiniformis* has spread beyond the original release sites independently of human facilitation to infestations of toadflax up to 60 kilometers away (Fig. 1). Considering the ability of *M. janthiniformis* to fly, it is to be expected that a mobile herbivore would move toward more ample food sources as carrying capacity of toadflax infestations is reached. The more extreme values of distance from the nearest release site may have resulted from wind-borne migration, or alternatively accidental human transport or non-reported releases.

There were five sites in the 2013 survey that were more than 30 kilometers from the nearest release, with the exception of one site, the other four were within 1.5 kilometers of another

Dalmatian toadflax population (ODA, 2011). Given that the median distance from release site was 1.5 kilometers in the 2013 survey data, it is probable that weevils have been traveling from one infestation to the next across Oregon, flying relatively short distances to incrementally expand their range. It is also feasible that wind-borne migration has facilitated the movement of *M. janthiniformis* across the state, with research showing that many species of insects use adaptive wind-borne migration to spread to new habitat (Gatehouse, 1997). There may have been a correlation early in the *M. janthiniformis* release program between the abundance of weevil and distance from release sites, but the distribution program and the natural weevil migration have obscured any correlation.

The management implications of the natural long-distance dispersal of an impactful biological control agent should be considered in future release programs of different agents that have similar migration potential. The 219 known releases may represent an over-application of weevils, and a use of resources that could have been utilized for other biological control programs or weed control projects. With tightening government budgets, establishing regionally successful "sources" by which the agent naturally migrates from to other regional infestations may represent a more cost-effective way of achieving successful biological control programs with reduced costs.

The control and spread capabilities of *M. janthiniformis* could support the grazing economy in Eastern Oregon which may be impacted if Dalmatian toadflax were left unchecked. The release form data shows that Dalmatian toadflax is primarily a rangeland weed in shrubland and grassland communities, where cattle production is often concentrated. At low densities, livestock can avoid the plant, and consequently its impacts are low. Conversely, at high densities cattle begin to be excluded from land once capable of being grazed (Lajeunesse, 1999). Determining the economic impacts of Dalmatian toadflax to grazing production due to displaced cattle and reduced land values would assist in further rationalizing the long-term economic benefits of biological control.

The relationships between terrain, vegetation type, land use, infestation type, and disturbance types relative to the density of Dalmatian toadflax were analyzed because they were found to be the most important in their propensity to affect the density and presence of toadflax infestations from a land manager's perspective (T. Butler, personal communication, June 13, 2013; Lajeunesse, 1999). They also help describe the environment in which infestations occur, and what type of disturbance may be facilitating infestations of toadflax. Importantly, these categories were also approachable by citizen scientists, allowing for a resource constricted to utilize citizen scientists as force multipliers across a large geographic area. This data illustrates the variation of environments at time of release of the biological control agent.

Impacts of toadflax infestations to biodiversity of infested areas have not been thoroughly studied, but there is ample evidence that ecosystems can have reduced plant community diversity when invasive species are present (Schooler et al., 2006; Groves and Willis, 1999). Because of the wide range of habitats that Dalmatian toadflax can occupy in natural areas that are often difficult to access for conventional management, the reduction of toadflax densities via biocontrol provides a landscape scale management approach that results in less competition of toadflax on desirable plant communities. Further study in determining whether there is a net benefit to desirable plant communities by measuring replacement vegetation at release sites would help quantify the net impacts to biodiversity due to biocontrol of Dalmatian toadflax.

The average densities across different ecological, geophysical and land use types indicates that Dalmatian toadflax can establish and flourish across a wide ecological threshold, and shows the resiliency of the weed to different environments. Utilizing *M. janthiniformis* as a control agent is a malleable control response to Dalmatian toadflax's wide ecological amplitude; the weevil has the ability to control the weed on a scale that is not economically viable through traditional control methods. ODA approximated the total cost for the *M. janthiniformis* release program to be $142,350 (T. Butler, personal communication, April 21, 2014). When framed relative to the costs, spatial and temporal constraints of conventional control, the *M. janthiniformis* release program has been cost effective and represents a spatially holistic approach to toadflax management.

There are additional studies that have also found that the weevil is an effective biological control against Dalmatian toadflax (De Clerck-Floate and Miller, 2002; Nowierski, 2004; Schat et al., 2011), in addition to it establishing regionally independent of human distribution (Van Hezewijk et al. 2010). From the evidence presented, there appears to be no ecological or financial incentive for ODA, APHIS and their partners to continue *M. janthiniformis* releases. Funding for further monitoring of ODA release sites would provide valuable information about population dynamics, and give further validation of this program's success. In the following decade, an additional efficacy review of this project should be conducted once the weevil-plant dynamics have reached a documented dynamic equilibrium. From all the evidence provided, it appears that the weevil will naturally continue to migrate to new infestations of Dalmatian toadflax, reach sufficient carrying capacity population levels for control, and migrate again to new infestations thus continuing its trend of expansion and inhibition of its target species: Dalmatian toadflax.

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Current Knowledge and Attitudes: Russian Olive Biology, Ecology and Management

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ABSTRACT

The primary goals of a two-day Russian olive symposium held in February 2014 were to disseminate current knowledge and identify data gaps regarding Russian olive biology and ecology, distributions, integrated management, and to ascertain the feasibility and acceptance of a proposed program for classical biological control of Russian olive. The symposium was hosted by the Northern Rockies Invasive Plant Council in conjunction with NRIPC's 3rd Invasive Species in Natural Areas Conference, held February 10-15, 2014, in Spokane, WA. Funding to support the Russian olive symposium was received through a USDA NIFA AFRI Foundational Program grant awarded in response to the 'Controlling Weedy and Invasive Plants' (A1131) program priority area. Talks delivered by invited research subject experts were interspersed with facilitated large group and smaller breakout group discussions. Key invited management and stakeholder representatives also discussed first-hand experiences with Russian olive as a conflict (invasive and beneficial) species in the western U.S., and provided details about the implementation and efficacy of current Russian olive IPM options. The symposium was ultimately initiated to help establish an atmosphere of dialogue and trust among researchers, policy makers, stakeholders and resource managers. This highly focused forum allowed participants to gain a common and updated understanding of many important aspects of the biology, ecology and management of Russian olive. This in turn contributed to productive dialogue, identifying, and hopefully mitigating conflicts of interests about the potential biological control of Russian olive.

Nomenclature: Russian olive, *Elaeagnus angustifolia* L. ELGAN

Key words: Russian olive, invasive species, wildlife habitat, weed biological control

INTRODUCTION

The scale, ecological value and vulnerability of landscapes affected, potential for unacceptable collateral damage to native flora and fauna, and attendant regulatory intricacies increase the operational challenges of herbicide-based management of riparian invasive species (e.g., Sheley et al. 1995; SERA 2011a, -2011b, -2014; Federal Insecticide, Fungicide, and Rodenticide Act [FIFRA]; Clean Water Act [CWA] and Endangered Species Act [ESA]). Under such circumstances, classical biological control can present an attractive alternative to current conventional options for sustainable management of widely distributed riparian invasive species. However, the spread and establishment of biological control agents do not stop at political or habitat boundaries and because their release is effectively irreversible, conflicting interests over the proposed use of biological control may and often do arise (Dudley and Bean 2012). Conflicting interests are further intensified when the plant species targeted for biological control is perceived to play an important beneficial economic or ecological role. Under these circumstances, the planned release of a classical biocontrol agent poses an unacceptable threat to a valued resource (Stanley and Fowler 2004; De Wit et al. 2001; Turner 1985).

Implementation of classical biocontrol of the invasive tree Russian olive, *Elaeagnus angustifolia* L. (Rosales: Elaeagnaceae) (ITIS 2015), currently faces a number of conflicting interests (Bean et al. 2008). Russian olive is thought to have been initially introduced to the U.S. in the 1800s as an ornamental (Hansen 1901). Until recently, Russian olive was recommended or supplied through state and federal agencies for windbreak/shelterbelt use and as wildlife habitat (Christensen 1963; Olson and Knopf 1986; Zouhar 2005). In upland, arid locales within the Northern Great Plains, such as eastern Montana, the Dakotas, and parts of Wyoming, few if any native trees grow and survive as well as Russian olive (Rundel et al. 2014; Stannard et al. 2002). The fruits of Russian olive, known as drupes, are utilized as food, shelter and perches by birds; 92 avian species have been associated with Russian olive in the Columbia Basin alone (Denny 2006). Hunters, outfitters and guides are strong proponents of Russian olive due to its reputation as an important source of both habitat and food for game species (Zouhar 2005). Farmers and ranchers value Russian olive because it provides shelter in summer and winter, protecting livestock from the hot summer sun and cold winter winds. For residents of this area, Russian olive is highly desired because it plays an important beneficial role, and is therefore rarely considered an invasive noxious weed (Sing and Delaney 2015, this volume).

Russian olive has escaped cultivation in disparate regions of its adopted North American range. In fact, nearby intentional planting of Russian olive was the most critical among a suite of eleven environmental variables predicting the occurrence and abundance of native and invasive riparian woody species (McShane et al. 2015). Widespread successful invasion, establishment and increasing dominance in western and southwestern riparian plant communities has led to Russian olive's current status as a state designated noxious weed (CO, NM, UT, WY), invasive species (CA, NE, WI), or regulated species (MT) (USDA, NRCS 2015a). Even east of the Mississippi River where an exotic congener, autumn olive (*Elaeagnus umbellata*), can be locally much more prevalent and invasive (http://www.eddmaps.org/), Russian olive is considered a noxious weed in the state of Connecticut. By 2002, Russian olive was found to be the fourth most frequently encountered and fifth most abundant western U.S. riparian plant species (Friedman et al. 2005). However, with plenty of currently unoccupied but suitable habitat for future range expansion, it could feasibly ascend in future rankings (Friedman et al. 2005; Reynolds and Cooper 2010; Jarnevich et al. 2011).

Russian olive can outcompete (but see Lesica and Miles 2004) and replace ecologically (Pendleton et al. 2011) and culturally (Pretty Paint-Small 2013; Zelitch 1970) important native trees and shrubs. Russian olive biological, ecological or life history traits conferring some degree of competitive advantage over native trees such as cottonwood include: seedling recruitment that is not limited to large flooding events; superior drought tolerance; seedlings that are comparatively less shade intolerant; and mature trees that are injured or felled much less frequently by beavers (Shafroth et al. 1995; Lesica and Miles 1999, -2001, -2004; Katz and Shafroth 2003; Reynolds and Cooper 2010). As a nitrogen-fixing species, Russian olive also potentially functions as a so-called 'transformer' invasive species (D'Antonio et al. 2004) due to its ability to alter both terrestrial and benthic nutrient and community dynamics in invaded riparian areas (Reynolds and Cooper 2010; Follstad Shah et al. 2010; Mineau et al. 2011, -2012).

Russian olive is not a consistently beneficial habitat component, and is more likely to be perceived or confirmed as a nuisance species where it becomes invasive and dominant, primarily in lowland, water proximate settings (Stannard et al. 2002; but see Espeland et al. 2014). In riparian areas, thickets formed from Russian olive trees armed with dense, spreading and thorny branches provide protected nesting sites to some species but may limit, even exclude access of larger stock and game animals to drinking water (Ghekiere 2008; Montana Audubon 2010).

Negative impacts of Russian olive are not always obvious, and are often indirect. Stoleson and Finch (2001) found that southwest willow flycatcher nests in Russian olive trees were more likely to be parasitized by the brown-headed cowbird (*Molothrus ater*) than nests placed in native tree species. Friesen and Johnson (2013) trapped more of the West Nile Virus (WNV) vectoring mosquito *Culex tarsalis* in Russian olive and caragana shelterbelts (n=183) than marsh (n=7) or grass (n=0) habitats in the Medicine Lake National Wildlife Refuge. Stoleson and Finch (2001) found that the mourning dove *Zenaida macroura* preferred to nest in Russian olive, utilizing it at a disproportionately higher rate than according to its relative availability; in their study, Friesen and Johnson (2013) identified mourning dove as the avian (and wildlife) species most frequently used as a host by blood-fed engorged *C. tarsalis*. Consequences of removing invasive species once native fauna have become acclimated or even dependent on the resources they provide must also be considered (Hultine et al. 2010). Smith et al. (2009) detected a drop in black-chinned hummingbird (*Archilochus alexandri*) nest survival following a fuels reduction program, which entailed removal of Russian olive and *Tamarix* spp. via single or combined mechanical, fire and herbicide treatments. Researchers concluded that nest placement in native cottonwoods post-treatment resulted in increased nest placement height, which was correlated with increased predation risk (Smith et al. 2009).

Riparian infestations of Russian olive are responsible for significant economic and resource losses (Wilson and Bernards 2009). Incursion of Russian olive trees, their roots and drupes into recreational areas, grazing lands, irrigation channels and in other waterways presents a chronic maintenance challenge to private and public land management (Lesica and Miles 2001; Olson and Knopf 1986). Russian olive fruits can spread along waterways (Lesica and Miles 2004) where seeds remain viable for an extended period (Pearce and Smith 2009). Consumption of the fruits by birds, wildlife and livestock does not necessarily compromise the viability of the seeds, which can lead to spread away from immediate riparian habitats (Edwards 2011; Katz et al. 2001). European starling, an abundant invasive species with a continental distribution, feeds extensively on Russian olive drupes (Edwards 2011) and may compete with native cavity nesting avian species for rare nesting sites (Johnson and Glahn 2005) in areas dominated by Russian olive because it does not typically form cavities.

Comparisons are often, and in some ways, erroneously drawn between a planned program for classical biological control of Russian olive and the troubled *Tamarix* spp. biocontrol program. In 1994 the tamarisk leaf beetles (*Diorhabda* spp.) gained formal approval from USDA APHIS PPQ for release as a classical biological control agent of *Tamarix* spp. in the western U.S. The southwestern willow flycatcher, *Empidonax traillii extimus* (Passeriformes) (http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=B094), one of four willow flycatcher subspecies (Federal Register 2013), was formally listed as an endangered species by the USDI Fish and Wildlife Service in 1995 (Federal Register 1995). The southwest willow flycatcher nests in *Tamarix* spp. in riparian areas throughout the southwestern U.S. where this weedy shrub/tree has replaced native willows and cottonwoods (Friedman et al. 2005). Both unassisted spread and deliberate and illegal southern redistributions of the biological control agent brought it into direct contact with this endangered avian subspecies (Bateman et al. 2010). Rapid defoliation or mortality of *Tamarix* spp. before adequate alternative nesting site trees become available for use by southwest willow flycatcher is a serious concern (Dudley and Bean 2012; Hultine et al. 2010). Acclimation of the southwest willow flycatcher to *Tamarix* spp. nesting sites may also have elevated the importance of this weedy species as a habitat component (van Riper III et al. 2008).

USDA APHIS PPQ effectively revoked prior approval for field releases of *Diorhabda* spp. in 2010 when it explicitly prohibited the interstate movement of these agents (APHIS 2010). The source of conflict in this case was obvious: biological control of an invasive tree species was eclipsed by a perceived need to protect the same invasive tree species from harm, due to the role it may currently play as a key component of an endangered species' critical habitat (Dudley and Bean 2012). Conversely, the desire of Northern Great Plains residents to preserve established Russian olive shelterbelts represents an aesthetic preference and a labor and money saving decision. The importance of aesthetic value should not, however, be under-estimated as it has been a significant source of stakeholder resistance to ongoing biological control of riparian *Tamarix* spp. (Hultine et al. 2014) and planned biological control of Russian olive. The rights of landowners to express their horticultural preferences vs. societal economic and ecological burdens imposed by invasive Russian olive presents a conflict of interest significantly different, but no less challenging, than that confounding *Tamarix* spp. biological control.

DeLoach (1981) discusses a similar conflict of interest over the hypothetical biological control of mesquite in the southwestern U.S., noting that although "total damage to the livestock industry probably exceeds direct beneficial values by 7 to 15 times," and that shade tree benefits to homeowners restricts biocontrol efforts to "organisms that attack only flowers, seed or young plants and thus limit the further spread of the weed." A similar tactic has been used in South Africa to curtail the unchecked spread of invasive *Acacia* spp. while avoiding harm to existing trees or stands deemed beneficial (Moran et al. 2003).

Conflicts of interest in weed biological control programs can be mitigated or avoided by bringing stakeholders together very early in the process of biocontrol agent development for a given target weed (Hayes et al. 2008). At that stage, dialogue can verify majority agreement on two key points: 1) that it is acceptable to release a biocontrol agent capable of spreading and interacting with a broad range of ecological receptors, wherever the target weed occurs throughout North America; and 2) that a monitoring plan needs to be in place that can effectively detect potential indirect or non-target environmental harm caused by the agent. Nontarget impacts need to be detected or identified as early as possible to determine a) whether the situation can be mitigated (e.g., with restoration following *Tamarix* defoliation by *Diorhabda*; Dudley and Bean 2012), and b) if the potential agent should be removed from further consideration as a viable management option against the target weed.

The primary goals of a two-day Russian olive symposium held in February 2014 were to disseminate current knowledge and identify data gaps regarding Russian olive biology and ecology, distributions, integrated management, and to ascertain the feasibility and acceptance of a proposed program for classical biological control of Russian olive. The symposium was hosted by the Northern Rockies Invasive Plant Council in conjunction with NRIPC's 3rd Invasive Species in Natural Areas Conference, held February 10-15, 2014, in Spokane, WA. Funding to support the Russian olive symposium was received through a USDA NIFA AFRI Foundational Program grant awarded in response to the 'Controlling Weedy and Invasive Plants' (A1131) program priority area. Talks delivered by invited research subject experts were interspersed with facilitated large group and smaller breakout group discussions. Key invited management and stakeholder representatives also discussed first-hand experiences with Russian olive as a conflict (invasive and beneficial) species in the western U.S., and provided details about the implementation and efficacy of current Russian olive IPM options. The symposium was ultimately initiated to help establish an atmosphere of dialogue and trust among researchers, policy makers, stakeholders and resource managers. This highly focused forum allowed participants to gain a common and updated understanding of many important aspects of the biology, ecology and management of Russian olive. This in turn contributed to productive dialogue, identifying, and hopefully mitigating conflicts of interests about the potential biological control of Russian olive.

CONFLICTING PERCEPTIONS OF RUSSIAN OLIVE

Keith Douglass Warner delivered the symposium keynote opening address: "Reframing the social values questions that underlie invasive plant conflicts: issues to consider for Russian olive." Warner illustrated how invasive species control is simultaneously an economic, ecological, and ethical act influenced by social values (Warner et al. 2008). Social values shape human perceptions of invasive species and control efforts taken against them. Participatory public engagement or 'buy-in' from the public on invasive species control is therefore of critical importance to avoiding or reducing conflicts of interest, through collaborative partnerships that engage the public, or at the very least, by actively seeking public input on control projects (Warner 2016 – this volume; Warner 2013).

Kevin Delaney (co-authors Erin Espeland, Andrew Norton, Sharlene Sing, Kenny Keever, John Baker, Massimo Cristofaro, Roman Jashenko, John Gaskin and Urs Schaffner), summarizing pros and cons in "Russian olive – a suitable target for classical biological control in North America?" affirmed the over-arching purpose of the symposium. Delaney proposed that by addressing and discussing potential conflicts of interest relatively early in the development of a Russian olive biological control initiative, delays or termination of a well-developed, heavily invested in biological control program could be avoided (Delaney et al. 2013). Specific points he asked participants to contemplate and discuss over the course of the symposium included: 1) negative and positive economic, environmental or social impacts caused by Russian olive in North America; 2) goals of Russian olive management; and 3) feasibility of classical biological control to achieve Russian olive management goals. He proposed that focusing on fruit-reducing agents might be a way to reach common ground among key stakeholders regarding Russian olive as a suitable target for biological control.

Sharlene Sing (co-author Kevin Delaney) presented results of an internet based survey to assess stakeholder attitudes toward Russian olive and Russian olive control, including classical biological control (Sing and Delaney 2016 – this volume). The objectives of the survey were: 1) to categorize stakeholders by geographic location, profession and professional affiliation; 2) to categorize stakeholder perceptions of Russian olive as a problematic and/or beneficial organism; 3) to assess the ecological, economic and geographic scale of perceived benefits and/or detriments associated with Russian olive; and 4) to have stakeholders identify potential benefits and/or risks that might arise from the implementation of a classical biological control program for Russian olive. An unanticipated outcome of the survey was its utility in identifying contentious issues and conflicts of interest; this information was then used to efficiently focus discussion where it was most needed, throughout the Russian olive symposium.

Janet Ellis identified steps taken by a stakeholder driven collective to reduce the spread and intensity of Russian olive infestations in Montana in spite of highly polarized opinions about its risks and benefits. The stakeholder group (Montana Native Plant Society; Montana Audubon) targeted making changes in state policy that would restrict the use and distribution of Russian olive. A petition (Montana Native Plant Society 2008) submitted to the Montana Department of Agriculture succeeded in having Russian olive placed on the Montana statewide noxious weed list as Priority 3 regulated plant (but not as a Montana listed noxious weed species). This designation represents a meaningful compromise between widely conflicting interests. According to the Montana Department of Agriculture's noxious weeds website (http://agr.mt.gov/agr/Programs/Weeds/PDF/2013WeedList.pdf), the risks posed by Russian olive are acknowledged without requiring action to be taken against existing trees: Priority 3 regulated plant species such as Russian olive "have the potential to have significant negative impacts. The plant may not be intentionally spread or sold other than as a contaminant in agricultural products."

RUSSIAN OLIVE BIOLOGY

Sarah Reichard used Russian olive as a case study of invasive plant life history traits that contribute to the successful spread and establishment of introduced woody species (Reichard and Hamilton 1997). For Russian olive, these included a comparatively brief juvenile period (3-5 years); ability to fix nitrogen; efficient seed dispersal from the parent plant; and phytochemical or mechanical (thorns) protection from predation/parasitism. Biogeographical traits correlated with invasiveness in weedy species were confirmed in Russian olive's wide latitudinal native (western to central Asia) and adopted (northern Canada to southern Texas) range, although its status as an invasive species in regions/continents other than North America was not significant. Russian olive's success in North America was primarily attributed to traits promoting reproduction and enhancing resistance to stress.

Gabrielle Katz (co-authors Jonathan Friedman and Patrick Shafroth) reviewed geographic and genetic influences on Russian olive phenology throughout its North American distribution. Thresholds in chilling requirements for Russian olive winter seed dormancy (Katz and Shafroth 2003) and spring bud burst were found to vary across the latitudinal gradient where this species occurs in the western U.S. Inadequate chilling results in reduced spring bud burst for trees at the southern-most extent of Russian olive's North American distribution limits. Katz's preliminary results suggest that natural selection may be acting on southern U.S. Russian olive populations, resulting in locally evolved reductions in chilling requirement. Further, under climate warming, these results suggest that the southern distribution of Russian olive may not necessarily contract if chilling requirement is an ongoing adaptation linking bud burst with appropriate local conditions; an expansion of the northern distribution remains probable.

Peter Lesica (co-author Scott Miles) discussed biological and ecological influences underlying Russian olive's replacement of native riparian cottonwood forests in the western U.S. Canopy cover, growth rate, age structure and damage associated with beaver activity for Russian olive, plains cottonwood (*Populus deltoides*) and green ash (*Fraxinus pennsylvanica*) were compared at 34 sites on the Marias and Yellowstone Rivers in eastern Montana. Results of this study indicate that Russian olive attains reproductive maturity at approximately ten years of age in Montana, with less than one new plant recruited per mature tree annually (Lesica and Miles 2001). Even though Russian olive was found to grow at nearly three times the rate of the native late-successional green ash at sites where both occurred, long maturation time and low recruitment rate characterize Russian olive invasion as slow compared to other exotic invaders. Beavers were found to play pivotal role in the dominance of Russian olive on the Yellowstone and Marias Rivers. On most river channels sampled, the majority of cottonwood trees occurring within 50 m, and 21% beyond 50 m, of the river channel were damaged by beavers; Russian olive suffered little damage regardless of location. Lesica and Scott concluded that cottonwood establishment and dominance are not precluded on unregulated rivers where flooding events reinitiate primary succession beyond the zone of beaver activity (Lesica and Miles 2001). However, because cottonwood establishment will often be restricted to lower terrace sites along regulated rivers, beavers will prevent cottonwood from developing a mature canopy close to the river and this will likely have little effect on the continued invasion of Russian olive (Lesica and Miles 2004).

GEOGRAPHIC SCALE OF THE RUSSIAN OLIVE INVASION

Linda Vance (co-author Claudine Tobalske) described how precise and accurate mapping of invasive species such as Russian olive is a necessary precursor to estimating habitat loss, recognizing spatial patterns in distribution and abundance, and identifying areas where targeted management efforts might be most effective (e.g., Vance 2005; Vance and Stagliano 2007; Vance et al. 2006) . Coarse scale, pixel-based spectral imagery classifications will likely suffice for applications where currency and repeatability are important. For other purposes, particularly at smaller spatial scales, classifications made using object-based high resolution imagery were recommended. Vance experimented with two broad approaches to mapping the extent and distribution of Russian olive in Montana's Yellowstone River Basin. Pros and cons and results obtained were compared using commonly available and easily manipulated Landsat 30m imagery vs. 1m National Agricultural Imagery Program (NAIP) aerial photography. Accuracy of Russian olive classification ranged from 80-96% across nine Montana rivers, including the Bighorn, Clark's Fork of the Yellowstone, Marias, Milk, Missouri, Powder, Tongue and Yellowstone. NAIP detected 6521 total Russian olive hectares in 2009, most of which were largely confined to eastern Montana. Plans are underway to redo mapping and analysis to compare past and present Russian olive distributions using current NAIP data. The proposed project will evaluate potential land use/attribute and spatial predictive factors. Methods will also be developed for distinguishing Russian olive from a closely related native congener, silverberry (Elaeagnus commutata), which is widely distributed in western Montana.

Jason Pither and **Liana Collette** found an increasing awareness and growing concern among Canadian invasive species managers regarding the potential threat Russian olive poses to riparian ecosystems within Canada. However, a lack of information about past, present, and forecasted future distributions, and known and potential impacts on native flora and fauna make accurately assessing the scope of the threat posed by Russian olive difficult. Findings concerning (i) historical shelterbelt plantings, (ii) niche model predictions of potential future distributions, and (iii) insect assemblages associated with Russian olive trees in the south Okanagan region of British Columbia are reported in Collette and Pither 2015. Maps depicting the extensive geographic scope of the Government of Canada's discontinued Prairie Shelterbelt Program (1901-2013), which resulted in the planting of 1,086,654 Russian olive seedlings, showed that Russian olive's current distribution and abundance is likely correlated with proximity to sites according to the number of Prairie Shelterbelt Program seedlings planted there in the past. So-called "remote surveys" exploiting Google Earth and Google Street View images were proposed, in addition to shelterbelt planting data, as a way to increase the number of available Russian olive occurrence records to meet record number requirements for ecological niche modeling. Remote surveys increased Russian olive occurrence records in southern British Columbia 5117%, from 29 (=shelterbelt planting data alone) to 1484 records (shelterbelt planting data supplemented with occurrence records generated via remote survey). Potential distribution of Russian olive across North America (focusing on Canada), derived from continent-wide planting/occurrence records and niche modeling predicted that a significant invasion would likely occur, based on habitat suitability, north along the Fraser and Thompson Rivers. Contrary to results reported from earlier U.S. studies, the richness, diversity and composition of insect assemblages associated with Russian olive were no different than assemblages associated with two commonly co-occurring native shrubs, Saskatoon (*Amelanchier alnifolia* Nutt.) and Woods' rose (*Rosa woodsii* Lindl.) (Collette 2014).

ENVIRONMENTAL IMPACTS OF RUSSIAN OLIVE

Graham Tuttle (co-authors Gabrielle Katz and Andrew Norton) described the effects of Russian olive and removal efforts on soil N, available light and plant community structure along the Arikaree and Republican Rivers in eastern Colorado. Russian olive plots consistently had twice the soil available N (ppm) and half the available light (relative PAR intensity) of reference plots. Reductions in resource availability under the influence of Russian olive resulted in lower native perennial grasses cover and greater annual grass and exotic forb cover than reported from comparable reference plots. Environmental variables contributing to the strength of the Russian olive effects were identified through non-metric multidimensional scaling (NMDS) with ordination and mixed-model ANOVAs. Position within the riparian system (channel bed vs. historic flood plain vs. perennial wetland), and the presence of gallery cottonwood forests influenced the magnitude of Russian olive's effect on available N, light and plant community composition. Russian olive presence was correlated with higher soil available N in channel bed plots than in historic flood plain plots. Both soil available N and available light were higher in open areas than under cottonwood forest. Elevated soil available N and available light translated into greater impacts on plant community structure in channel bed and open plots. Overall, impact of Russian olive on ecosystem processes was found to be highly context dependent, with greater effects on both biotic and abiotic responses on sites that had higher resource water and light availability (Tuttle et al. 2012).

Susan Lenard (co-authors Paul Hendricks and Linda Vance) investigated impacts of Russian olive replacement of riverine stands of plains cottonwood on bats in southeastern Montana. Electronic bat detectors used to measure the relative activity of bats in stands dominated by plains cottonwood or Russian olive along the Yellowstone and Powder Rivers in southeastern Montana. Bat species detected in 18 stands (12 cottonwood, 6 Russian olive) included the silver-haired bat (*Lasionycteris noctivagans*), big brown bat (*Eptesicus fuscus*), western small-footed myotis (*Myotis ciliolabrum*), western long-eared myotis (*Myotis evotis*), little brown myotis (*Myotis lucifugus*), and Townsend's big-eared bat (*Corynorhinus townsendii*) (the latter two are Montana species of concern - http://mtnhp.org/SpeciesOfConcern/?AorP=a). Although bats were detected in all stands, their activity was greatest in stands dominated by cottonwood, positively correlated with percent canopy cover of cottonwood, and negatively correlated with percent canopy cover of Russian olive. Russian olive is shorter (14 vs. 25-30 m), forms a denser canopy, has thorny (vs. thornless) branches, has much harder wood and thinner bark than the plains cottonwood. Stand attributes beneficial both to bat flight and roosting, and to cavity nesting for native bird species such as northern flicker, downy woodpecker, hairy woodpecker, red-headed woodpecker, white-breasted nuthatch, black-capped chickadee and red-breasted nuthatch, were most prevalent in cottonwood stands (Hendricks et al. 2012). Degradation of bat habitat may amplify threats posed by white-nose syndrome (WNS). WNS has already been confirmed in the big brown bat and little brown myotis, while the causative fungus of WNS, *Pseudogymnoascus destructans*, has been detected on the silver-haired bat but with no diagnostic sign of WNS documented thus far (https://www.whitenosesyndrome.org/about/bats-affected-wns).

Colden Baxter (co-authors Madeline Mineau and Kaleb Heinrich) contextualized riparian invasions of exotic terrestrial species such as Russian olive by focusing on the coupled vulnerability of land and water. Nitrogen subsidies leaching into streams, a consequence of Russian olive's ability to fix dinitrogen (N_2), can alter stream nutrient dynamics. Stream reaches in Idaho and Wyoming invaded by Russian olive had higher organic nitrogen concentrations and exhibited reduced nitrogen limitation of aquatic primary producers, compared to reference reaches (Mineau et al. 2011). Decomposing leaves and drupes falling from streamside Russian olives, an abundant allochthonous energy source, can alter stream organic matter budgets. A pre- and post-invasion comparison determined that Russian olive invasion was associated with a nearly 25-fold increase in recalcitrant stream litter input. Russian olive inputs were additionally associated with a 4-fold increase in streambed stored organic matter, but with no attendant changes in gross primary production or community respiration, estimated stream ecosystem efficiency declined by 14% (Mineau et al. 2012).

Inputs from Russian olive may also alter the composition of food resources for both native and nonnative benthic fauna, and thereby influence their abundance and productivity. No significant change was detected in the total secondary production of invertebrates in response to the altered food base (e.g., Russian olive litter subsidized stream and streambed), although there were changes in some individual taxa. The results of dietary and stable isotope analysis indicate that dominant, native macroinvertebrates selected Russian olive litter at a rate below what would be expected based on proportionate availability as a food source (Mineau 2010; Mineau et al. 2008).

Unlike most co-occurring native fish species, invasive carp (*Cyprinus carpio*) are armed with large "pharyngeal" teeth that can be used to crush and derive energy from Russian olive drupes (Taylor 2013). Carp densities have increased significantly following Russian olive establishment while the abundance of native fish has declined over the same period. Increasing water turbidity through feeding-related disturbance and fecal contributions to streambed sediment, carp have significant negative impacts on native fish species that thrive best in cool, clear water. Carp eggs, fry and juveniles function as a prey subsidy for nonnative predators such as bass and perch, which may also enhance within and between trophic level pressures on already challenged native fish species.

Richard Fischer discussed investigations of bird community response to vegetation cover and composition in riparian habitats dominated by Russian olive. Concerns about potential degradation of wildlife habitat were weighed against benefits such as habitat structure, food and cover provided by Russian olive in a subset of seven out of more than 50 Habitat Management Units (HMUs) along the Snake and Columbia Rivers. These HMUs are managed by the U.S. Army Corps of Engineers (USACE) to mitigate the loss of wildlife habitat to inundation, the result of dam construction on the lower Snake River. Southeastern Washington breeding and winter riparian bird community response to spatial variation in vegetation cover, including variations in the proportion of Russian olive cover, were assessed.

Summer and winter bird surveys and remotely sensed (IKONOS/Worldview) vegetation assessments generated data for 181 breeding bird points and 172 winter riparian bird points (Fischer et al. 2012). Analyses included 51 avian species, of which 5 were deemed riparian-dependent breeding species. Total woody vegetation cover on the 353 points included in the analyses ranged from 0-100%, with a median value of 35%; Russian olive composition ranged from 0-100%, with a median value of 89%. Total woody cover influenced avian density, richness and summer composition, which peaked between 50-70%, regardless of Russian olive proportion contributing to total woody cover.

HMU stewardship by USACE needs to strike an informed balance between effective management of invasive riparian plants such as Russian olive, and reducing unintended or undesirable wildlife or wildlife habitat impacts resulting from weed management activities. Spatial removal guidelines for woody riparian species in particular were found to be lacking. A study was therefore recently initiated to investigate and identify the most cost- and ecologically- effective spatial configurations for Russian olive removal, for the purposes of ecosystem restoration, on USACE-managed lands. Flora and fauna were monitored pre- and post-removal on randomly selected plots superimposed on irrigation circles within study HMUs. An equal number of plots were set aside as controls as the number receiving a range of spatial removal treatments. Treatments included the following spatial removal configurations: 'clump cutting' to reduce Russian olive to 40% cover; removal of Russian olive from two of four quadrants in the irrigation circle, again reducing Russian olive cover to 40%; removal of Russian olive from one of the two semicircles bisecting the irrigation circle plot, to achieve a Russian olive cover of 40%; and no Russian olive removal (control). Control plots were randomly selected but conformed to three cover classes of Russian olive (all n=9): 20-40%, 41-60% and >60%.

MANAGEMENT OF RUSSIAN OLIVE: REMOVAL PROJECTs

Lars Baker (co-authors Michael Wille and James Leary) presented results of a study evaluating the usefulness of herbicide ballistics technology (HBT) (Leary et al. 2014), which uses paintball guns to deliver metered doses of herbicide to individual trees, for control of salt cedar and Russian olive. One hundred plants of each species were selected for treatment along Five Mile Creek, a tributary to Boysen Reservoir, located 20 miles north of Riverton, WY. Efficacy of HBT herbicide applications was compared to percent kill attained through standard foliar, cut stump and basal bark applied treatments. 2 ml paint balls were loaded with 25% triclopyr in basal oil (~ 10% a.i.) or 25% imazapyr in basal oil (~ 5% a.i.) and fired using compressed air at the target plants, releasing the treatment on impact. Treatment doses used, as paintball number equivalents of volume of herbicide/oil solution, were as follows: 6 paintballs (=12 ml of herbicide/oil solution), 12 (=24 ml), 18 (=36 ml) and 24 (=49 ml). Herbicide-loaded paintballs were applied to one side of treated plants, aimed to hit the trunk at 0.3-0.5 m above ground. Treated plants were evaluated at 12 and 24 months after treatment.

Triclopyr efficacy against salt cedar was found to be good overall, except for foliar applications (foliar: 0%; basal bark: 100%; cut stump: 100%; HBT: 81-98%). Efficacy of HBT applications of triclopyr on Russian olive was generally poor: 44-75% kill was attained with paintball-applied trunk treatments, improving to 60-80% kill when treatment was applied to the foliage. Imazapyr treatments produced less consistent results on both salt cedar (foliar: 94%; basal bark and cut stump: 25% and 60%; HBT: 30-50%) and Russian olive, and also resulted in non-target injury to nearby plants. Efficacy of HBT applications of imazapyr on Russian olive (paintballs/kill) ranged from 13-38% using 6-24 paintballs. Based on these results, the authors thought it would be worthwhile to develop a dose response curve for HBT application of triclopyr/basal oil on salt cedar that could be used to fine tune the application method and rates to get results comparable with currently labeled basal bark and cut stump applications, while using a significantly reduced amount of active ingredient. The estimated reduction in the amount of herbicide/oil mix used per treated salt cedar tree would be 24-49 ml using HBT vs. 355 ml for basal bark treatment might offset the increased cost of HBT ($3.27-$7.44 vs. $1.17). HBT applications of herbicide on salt cedar control would be particularly useful against trees that are sparse, have a scattered distribution, or occur in remote or difficult to access locations. Efficacy of HBT applications on Russian olive was generally low and inconsistent with both herbicides, using the application rates stated above, possibly because several hits were required to breach the bark.

Jim Ghekiere (co-author Warren Kellogg) presented results of an ongoing, innovative demonstration project initiated in 2008 by the Marias Watershed group to evaluate costs, logistics, and operational issues associated with a full-scale Russian olive removal project on the Marias River. The overarching goal of the project was to compare available technologies and approaches for Russian olive removal from a riparian area. The project demonstrated and evaluated Russian olive removal treatments for success and cost effectiveness, to be used as a model to inform future removal projects along the remaining untreated stretches of the Marias River, and on other affected rivers/streams throughout Montana. Control methods demonstrated in the project included: basal bark herbicide treatment, cut-stump herbicide treatments following cutting with a gyro-track mulcher, cut-stump herbicide treatments with “hot-saw” cut trees, cut-stump herbicide treatments with chain saw cut trees, foliar application of herbicide to seedlings, and foliar applications of herbicide to mature trees. Cut-stump and basal bark treatments used a 1:3 mix of triclopyr and basal bark oil.

Poor control was obtained with treatments that involved cutting or mulching trees to ground level. Extensive damage to stumps, nearly complete removal of bark and destruction of the cambium layer under the bark resulted when the mulcher was used. Loss of the bark and cambium layer, critical respectively for herbicide uptake and translocation, resulted in the emergence of thick, bushy regrowth from stumps the following year. Conversely, herbicide uptake and translocation was highly successful in trees cut cleanly to a height of 18-24 in then treated with herbicide. Treatment efficacy was 90-95% in the first year on all trees that had been cut cleanly, leaving the bark intact, whether cutting was by hot-saw, chain saws, or pruners. Results varied with the age or size of treated trees: basal bark treatments on mature trees with trunks over 3” in diameter that had not been cut yielded poor results, while foliar treatments were generally successful on young trees and seedlings.

Landowner cooperators have agreed to participate in the removal project along 49 miles of the Marias River, and 10 miles of Pondera Creek. Stakeholder assessment of the project was accomplished through weed tours and float trips before (2007) and after treatments were initiated (2009, 2013). To date, removal has been completed on 29 miles of the Marias River and 10 miles of Pondera Creek; Russian olive has also been inventoried on the next 19 miles of the Marias River. Prospects for the continuation of this project are positive due to the combined commitment and ongoing support of local federal agency (USDI Bureau of Land Management) and private land owners and managers.

Erin Espeland (co-authors Mark Peterson, Jennifer Muscha, Robert Kilian and Joe Scianna) discussed known and potential ecosystem effects of Russian olive control, in this case, removal followed by re-vegetation. Alterations in canopy architecture and secondary weed invasions following re-vegetation were identified as potential influences that may mediate changes in the abundance and diversity of arthropods, birds and mammals, soil processes, and forage quality and quantity following the control of Russian olive via removal and re-vegetation treatments. Vegetation, soils, and insect data were recorded from four 1.2 acre plots before Russian olive was removed in April 2011, to compare trajectories in these communities to trajectories in nearby reference plots where Russian olive was not removed. Removal using a tree shear followed by immediate application of a 1:3 mix of triclopyr to basal bark oil was effective. A significant flooding event in May 2011 likely facilitated re-sprouting from roots in 3.9% of the 2500 total cut and herbicide treated trees. The same flooding event may have led to the 2-fold increase in densities of Russian olive seedlings on removal plots compared to reference plots, in fall of 2011. Because high densities of tamarisk seedlings were similarly detected in removal plots, a foliar treatment of 1 oz triclopyr: 3 tsp aminopyralid mixed with >1 oz of surfactant was applied to all weedy trees in removal plots in 2012 and 2013.

Each of the four removal plots was divided into five sub-plots which were assigned the following re-vegetation treatments in spring 2012: 1) herbs, a mix of 4 native grasses: slender wheatgrass (*Elymus trachycaulus*), western wheatgrass (*Pascopyrum smithii*), prairie cordgrass (*Spartina pectinate*) and switchgrass (*Panicum virgatum*), and 9 native forbs: western yarrow (*Achillea millefolium*), dotted blazing star (*Liatris punctate*), prairie clover (*Dalea* spp.), prairie coneflower (*Ratibida* spp.), Maximillian's sunflower (*Helianthus maximiliani*), Canadian milkvetch (*Astragalus canadensis*), prairie thermopsis (*Thermopsis rhombifolia*), echinacea (*Echinacea* spp.), and Lewis flax (*Linum lewisii*), 2) herbs + 4 native shrub species: golden currant (*Ribes aureum*), chokecherry (*Prunus virginiana*), buffaloberry (*Shepherdia* spp.) and Woods' rose (*Rosa woodsii*), 3) herbs + 4 native tree species: narrow leaf cottonwood (*Populus angustifolia*), plains cottonwood (*Populus deltoids*), boxelder (*Acer negundo*) and ash (*Fraxinus* spp.), 4) herbs + shrubs + trees, or 2) control, with Russian olive removed but no re-vegetation. No significant difference in understory cover between control and re-vegetated subplots was detected by the second year of the study, in spring 2013. Establishment of seeded herbaceous species on re-vegetated subplots in the initial year of the study was very low due to drought conditions, overall slowing re-vegetation with this functional class. Shrub and tree survivorship ranged from 50.5-92.4% and 25.0-84.6%, respectively, and was not enhanced by the use of weed fabric.

Soil analyses indicated no response of nematodes, fungi, or ciliates to Russian olive removal. However, because soil bacteria communities showed opposite trajectories in removal and reference plots, future investigations on how Russian olive removal impacts soil functions such as decomposition and nutrient availability will focus on bacterial communities. Additional reference plots will be added to the study because the original reference plots experienced a different flooding history than the removal plots in spring 2011. Investigation of potential ecosystem effects of foliar applied herbicides will be expanded because this type of treatment leaves no slash piles but standing Russian olive snags retain beneficial tree architecture. Analysis of insect community data from sweep and pitfall samples, and game camera data will be used to determine if animal utilization of removal areas differs from Russian olive-dominated areas.

Scott Bockness (co-authors Amy Ganguli, Jack Alexander and Gary Horton, Jr.) reported results of innovative conservation approaches, including prevention and control, biomass utilization/bioenergy generation, to the management of Russian olive and salt cedar infestations affecting the Missouri River watershed (Rindos et al. 2014). The project incorporated short- and long-term vegetation monitoring to evaluate ecological changes, riparian system health and function, and natural resource enhancement following the treatment of invasive plants. A consultant partner, Synergy Resource Solutions Inc., completed baseline monitoring on treatment and control sites to evaluate pre- and post-treatment conditions of the target weeds and the wider vegetation community, and to demonstrate the long-term efficacy of treatment methods and the influence of initial site conditions on results attained. Cut-stump and basal bark treatments were successful but areas treated with mulch removal (mechanical mastication) alone and no application of herbicide experienced high regrowth, which required unplanned follow-up applications of herbicide (Bockness et al. 2013). On all study sites, follow up treatments of non-target weedy species were essential to facilitating the establishment, re-establishment or increases in desirable plant species. On one site, Russian olive cover of 80.7% in 2012 declined to 0% in just one year following removal and herbicidal treatment. On the same site, tall wheatgrass production increased more than three-fold following Russian olive treatment. Post-treatment production of tall wheatgrass increased from 1,437 lb/acre in 2012 to 3,050 lb/acre in 2013, and to an estimated 5,400 lb/acre in 2014 (Sterling et al. 2014).

Woody biomass of native tree species, acquired as a byproduct of forest management activities, has been a common fuel source for heat and power generation over the past two decades in the western United States. Russian olive and saltcedar biomass harvested following cut-stump and herbicide treatments were tested to determine their potential utilization as the raw materials or ‘feedstock’ for biofuel energy applications. Extensive independent testing confirmed that biomass resulting from herbicide-treated trees did not contain high levels of toxic residues; that it could be safely used as a bioenergy source; and that it had heat/energy values comparable to other currently used biofuel sources. Russian olive BTUs (8,055) were lower but comparable, with an average calorific value of 90.2% of traditional forestry species, to a range of tree species commonly used as a source of biofuel (Douglas fir - 9,050 BTUs); ash produced from Russian olive was low at 1%, compared to 1.1% for Douglas fir. Results of ash fusion tests indicate that the ash fusion temperature of Russian olive at 2700°F is high enough that when burned, would be unlikely to cause fouling or the formation of “clinkers” in typical biomass fueled systems. However, costs associated with harvesting and transporting saltcedar and Russian olive biomass to the limited number of regional biofuels facilities currently available suggests that until local/area users are developed, this will not a cost-effective source of biofuel.

Detailed descriptions of all aspects of this project and results are disseminated through a dedicated website available online at www.weedcenter.org/mrwc/cig

RUSSIAN OLIVE REMOVAL PROJECTS: COMMUNITY RESPONSE

Lindsey Woodward recounted high and low points in Hot Springs County Weed and Pest Control District’s battle against Russian olive and tamarisk invasions, which has been ongoing since 2003. County efforts to remove Russian olive and tamarisk from tributary drainages of the Bighorn River contributed to a larger management project extending throughout the Bighorn Basin, culminating in the removal of both invasive tree species from the river corridor (USDA NRCS 2015b). Project partners included Big Horn Basin Weed and Pest Districts and Weed Management Associations, ditch companies, USDI Bureau of Land Management, Wyoming state lands, USDA Natural Resources Conservation Service, Wyoming Wildlife and Natural Resources Trust, Wyoming Game and Fish Department, along with numerous private landowners. In 2011, target weed populations were mostly cleared from tributary drainages and the reintroduction of natives was well underway. The next phase of the project, large scale removal projects on the Bighorn River, began in 2012 with funding from a number of partners in place. Up to that point, response from the residents of Hot Springs County Weed and Pest Control District had been almost entirely positive, and those who opposed the removal of Russian olive and tamarisk were able to opt out of control programs. However, opposition to the project began to mount as large scale, highly visible work progressed on the Bighorn River. Opposition to the project became increasingly pronounced and aggressive, but fairly creative in nature, with highly motivated opponents reaching out to like-minded residents through novel vehicles such as classified ads and a Facebook page. The most common source of dissatisfaction with the project arose from the widely-held perception that Russian olive and saltcedar removal was depleting wildlife habitat. Rehabilitation of affected areas is an important component of responsible invasive plant management, especially in ecologically sensitive habitats. However, full recovery of functional and aesthetic values following treatment and restoration occurs at a range of highly site-specific spatial and temporal scales. Residents initially opposed to the removal program were more likely to reconsider and give weed control agencies a chance to help with habitat recovery once the full details of the program, especially rehabilitation efforts, were communicated. The range of effects that rehabilitation of Russian olive and tamarisk infested areas will have on wildlife within the Big Horn Basin, similar to the restoration of vegetation on along the river corridor, will likely take some time to be fully realized.

Josh Shorb discussed progress made by the Shoshone River and Clarks Fork River Coordinated Resource Management (CRM) program, which was created in 2010 to focus on the control of Russian olive and salt cedar (Parsons 2010). Initial financial support to fund the project's original treatment goal, to remove 5,000 consolidated acres of Russian olive and saltcedar, came through a $300,000 Wyoming Wildlife and Natural Resource Trust Fund grant which was matched to total $824,719.65, including funding from USDA NRCS, Park County Weed and Pest District, and significant landowner cash ($148,494.15) and in-kind ($82,691.83) contributions. The project's goal, to eradicate as much Russian olive and salt cedar as possible, would return invaded riparian areas to fully functioning, native species dominated ecosystems. Shoshone River expanses targeted for treatment as part of the CRM project began at the Buffalo Bill reservoir and continued to the Park/Big Horn county line, and included all major tributaries. Affected areas along the Clark's Fork to be treated as part of the project began at the Clark's Fork Canyon and extended to the Wyoming/Montana state line, and included all major tributaries. From its inception, this project faced many challenges as residents' opinions about removing Russian olive and salt cedar varied wildly. Landowners supportive of the project began treatments as soon as funding was available. Landowners opposed to the project declined to participate in any aspect of Russian olive and saltcedar control. Despite the availability of funding, as of January 2014, which was five years after the first coordinated removal efforts began in 2009, only 1,445.6 consolidated acres of Russian olive and 32 acres of saltcedar had been removed. The most significant challenge to the successful execution of this project proved to be the wide divergence of opinion or values assigned to Russian olive and saltcedar. Some residents viewed the trees as noxious weeds, while many others perceived them to be essential components of critical wildlife habitat. Vociferous and emotional public opposition to this project was therefore undoubtedly motivated by the high stakes believed to be at risk.

Steve Brill hosted a screening of a video that he appears in, "River of Time, Wyoming's Evolving North Platte River" (McMillen 2012). The narrator begins by contextualizing invasive tree management programs in neighboring southeast Wyoming counties, reviewing facts while compelling images aptly convey the origin, history and importance of the North Platte River. Goshen, Platte, Converse, Natrona and Carbon counties, the five Wyoming counties that the North Platte River flows through, consolidated efforts in 2007 to control riparian infestations of Russian olive and saltcedar by forming the Upper North Platte River Weed Management Area (Duncan 2012). Upper North Platte River WMA partners include private landowners, USDI Bureau of Land Management (BLM), Bureau of Reclamation (BOR) and National Park Service's Northern Great Plains Exotic Plant Management Team (NGP-EPMT), Wyoming

Game and Fish, USDA Natural Resource Conservation Service (NRCS), affected Wyoming Conservation Districts and County Weed and Pest Districts, Wyoming Department of Agriculture and others. Alterations in the functioning and services provided by natural and managed ecosystems affected by Russian olive and saltcedar invasions along the Upper North Platte River WMA are identified, and short- and long-term ramifications of these alterations are explored. Since its inception in 2007, WMA partners have treated more than 4,400 acres of saltcedar, and 2,800 of Russian olive; pros and cons of these efforts and the techniques used are discussed. Residual woody biomass generated through removal projects remains an ongoing and pressing issue. The video was produced and directed by Becky McMillen, Insight Creative Independent Productions of Scottsbluff, NE, and is available for viewing free of charge online at: http://www.icindie.com/riveroftime.html

MANAGEMENT OF RUSSIAN OLIVE: BIOLOGICAL CONTROL

Dan Bean (co-author Tom Dudley) discussed first-hand lessons learned from the ongoing *Tamarix* biocontrol program and their relevance to the nascent Russian olive biocontrol program (Bean et al. 2008). Lessons learned from the *Tamarix* spp. biocontrol program included: 1) although biocontrol programs and the Endangered Species Act may share the same long term goals, conflict will be inevitable in the short term; 2) biocontrol is safe because host range testing (of candidate biocontrol agents) is so accurate and conservative; 3) the trajectory of biocontrol programs are predictable, not 'haywire' ('haywire' according Dr. Robin Silver, a retired emergency-room physician in Phoenix, professional wildlife photographer, and co-founder of the Center for Biological Diversity in a press release issued September 30, 2013 "Lawsuit Filed to Save Endangered Southwestern Songbird From Habitat Destruction Caused by Invasive Beetles" http://www.biologicaldiversity.org/news/press_releases/2013/southwestern-willow-flycatcher-09-30-2013.html); and 4) although the time scale of biological control is difficult, given institutional attention span, stakeholder enthusiasm does not wane.

Regarding the goals of biological control: goals and pathways to achieve them need to be clear and well-articulated. The goals of classical biological control of weeds are ultimately dictated by the trenchant, chronic and sustained nature of target weed infestations; eradication is not a realistic, or in certain cases, even desirable aspiration. Suppression of well-established, widely distributed target species below economically and ecologically damaging thresholds to achieve non-dominant representation within mixed vegetation assemblages, is particularly important when native species become acclimated to their presence and use. Reductions in the proportionate contribution of *Tamarix* and Russian olive to total composition of woody riparian species, and not eradication, will therefore continue to be the goal of biological control of these two target species, especially within southwest willow flycatcher nesting habitat.

Regarding the safety and trajectory of biological control: biocontrol requires a higher level of stakeholder and public education than conventional weed control. Classical biological control involves the consideration of many more interacting and complex factors (e.g., agent population dynamics and dispersal) than chemical or mechanical control. An under-informed public may be more susceptible to unsubstantiated, sensationalist negative publicity. Of the more than 300 special insects assessed during the foreign exploration phase of the *Tamarix* biocontrol program, only four, including the *Diorhabda* complex, were judged to be safe enough to undergo extensive host specificity testing.

Regarding the time scale of biological control: the nature, scale and duration of biological control projects make collaboration essential. The first stage of biological control programs, objectively confirming the appropriateness of targeting the species for biological control, then identifying and assessing the safety and efficacy of candidate agents, involves an investment of time and funding that necessitate collaboration. The second stage of biological control programs, documenting the candidate agent's biological responses and ecological interactions under novel (North American vs. native range) field conditions is another herculean task requiring extensive collaboration. The third stage of biological control programs, implementation, moves beyond the focused study of the agent and characterizing the range of its interactions with the target weed and other ecological receptors. Implementation at the most basic level involves figuring out how to best use this new 'tool' (i.e. the biocontrol agent) to control the target weed. Developing optimal protocols for 'applying' and evaluating the control efficacy of the agent released to address diverse management needs also requires a significant collaborative effort. Long term commitment by end users and participating land management entities is critical for the success of inherently long term projects such biological control. Long term commitment to funding, collecting, analyzing and publicizing relevant and high quality ecological monitoring data is particularly important for identifying and responding to unanticipated impacts and interactions. As an example, unanticipated rapid increases in the density and spread of *Diorhabda* resulting from initial U.S. field releases significantly impacted *Tamarix* within the nesting range of the southwest willow flycatcher well before the estimated 10-20 year lag between releases of the first beetles and when restored bird habitat was thought to be required (Dudley and Bean 2012). Field data have also refuted a number of predictions about *Tamarix*, *Diorhabda* and how their ongoing interactions impact the southwest willow flycatcher.

Notable controversies that arose during the development of the *Tamarix* biocontrol program involved contradictory assessments of 1) the value of *Tamarix* as a wildlife habitat component, particularly for the endangered southwestern willow flycatcher; 2) the potential for biological control of *Tamarix* to result in water savings; and 3) the long term outlook for riparian restoration in the presence of *Tamarix* biocontrol. Value of basic and applied research, site monitoring, stakeholder consortia, public education and the engagement of policy makers in the tamarisk biocontrol program were discussed with a view toward the future and potential success of Russian olive biological control.

Urs Schaffner (CAB International in Délémont, Switzerland) delivered the symposium keynote closing address, discussing the potential for classical biological control when the target is a 'conflict species', as has become the case with Russian olive. Russian olive originates from central Asia, with a native range extending into western and eastern Asia. Russian olive is a characteristic species of the *tugai*, an imperiled riparian forest ecosystem unique to the continental, winter-cold deserts of Central Asia. *Tugai* forests consisting of fast growing deciduous tree species such as poplar (*Populus euphratica*, *P. pruinosa*), Russian olive and willow (*Salix* spp.) historically occupying the flood plains and deltas of the Amu Darya, Syr Darya, Zaravshar and Vaksh Rivers have nearly disappeared due to Soviet-era afforestation, intensified agriculture and alteration of hydrological regimes (Tupitsa 2007). Russian olive has been exploited for many purposes in the native range: orchards are planted with cultivars developed to express fruit characteristics that enhance their attractiveness for human consumption; trees are also planted to function as windbreaks, shelterbelts, and as shade trees; and woody biomass is used as a source of fuel. The perception that Russian olive in North America also confers significant ecological and anthropogenic benefits continues to be strongly and widely held throughout the western and southwestern United States.

Although the general goal of biological control is constant, to reduce the density and spread of the target organism below ecological or economic thresholds, the goal or goals of weed management programs are often un- or under-defined. Similarly, biological control intended for use as a stand-alone treatment is subject to far fewer practical restrictions in implementation but may be too slow-acting or unable to achieve adequate control than if it was used as a component of integrated weed management; this aspect of the weed management program should be defined *a priori* implementation or treatment. In all cases, the underlying purpose of biological control should be habitat management, specifically to use biological control to retain or cause a defined habitat benefit. The capabilities of the agent should also therefore be matched to the desired habitat benefit.

To date, extensive native range surveys have identified more than 60 invertebrates associated with Russian olive (Schaffner et al. 2014). However, conflicting interests over the proposed release of biological control agents against Russian olive have restricted initial investigations to candidate agents to those that would reduce seed production and thereby the spread of Russian olive through seeds, without killing established trees. Two invertebrate species have been selected for in-depth study: the mite *Aceria angustifoliae*, which attacks leaves, inflorescences and young fruits of Russian olive, and the moth *Ananarsia eleagnella*, which mines the shoot tips and the fruits of Russian olive trees. The selection of these two candidate agents assumes that Russian olive invasion of North American riparian habitats has occurred through seed dispersal, so invasion processes can be slowed or stopped by reducing propagule pressure.

The symposium concluded with the development of a strategic approach to coordinating data collection on knowledge gaps revealed through the previous two days of presentations and discussions. The goal of the data collection would be to provide scientific evidence to answer lingering questions about the drivers of Russian olive invasion in riparian ecosystems, environmental impacts of Russian olive invasion, socio-economic implications of Russian olive invasions, and management options for Russian olive invasions.

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Stakeholder Perceptions: Biological Control of Russian Olive *(Elaeagnus angustifolia)*

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ABSTRACT

An online survey was distributed through email lists provided by various stakeholder groups on behalf of the International Consortium for Biological Control of Russian Olive in spring of 2012. A total of 392 respondents replied from 24 U.S. states and 1 Canadian province. Questions posed in the survey were designed to identify and categorize 1) stakeholders by geographic location, profession and professional affiliation; 2) stakeholder perceptions of Russian olive as a problematic and/or beneficial organism; 3) by ecological, economic and geographic scale stakeholders' perceived benefits and/or detriments associated with Russian olive; and 4) potential benefits and/or risks stakeholders thought might arise from the implementation of a classical biological control program for Russian olive. The survey also asked stakeholders to suggest additional research to improve understanding both of Russian olive and Russian olive biological control. The survey link was widely distributed and respondents were given from February through May 2012 to complete the questionnaire. The questionnaire was highly informative because it included many opportunities for respondents to provide detailed responses in their own words.

Nomenclature: Russian olive, *Elaeagnus angustifolia* L., ELGAN

Key Words: Conflict of interest, survey, weed biocontrol, non-target impacts, wildlife habitat, wildlife resources, shelterbelt, riparian, restoration

INTRODUCTION

The date and location of Russian olive's (*Elaeagnus angustifolia* L.) initial introduction to North America is unknown. Some of the earliest U.S. introductions are anecdotally attributed to German settlers who brought plant material from Russia when they immigrated to South Dakota in the late 1800s (Hansen 1901). Russian olive was highly recommended for planting by a number of western and south western state horticulturalists in the early 20th century (Christensen 1963). Thereafter it was widely planted throughout the west, south west and mid-west as an ornamental and shade tree, in windbreaks, for erosion control, and more recently, for wildlife habitat enhancement and as a nectar source for honey bees (Olson and Knopf 1986; Zouhar 2005). Escape from cultivation, a highly likely consequence of Russian olive's popularity and utility, was first reported in 1924 (Christensen 1963). Russian olive is now estimated to be the fifth most abundant riparian plant species in the western United States (Friedman et al. 2005), and is considered naturalized in at least 17 U.S. states (Olson and Knopf 1986) and five Canadian provinces (Katz and Shafroth 2003).

Russian olive has spread and become locally dominant to the extent that its negative economic and environmental impacts frequently outweigh its benefits. Russian olive poses a significant threat to biodiversity on western North American floodplains, and could eventually dominate Montana's Milk River and Marias River floodplain ecosystems to fully replace plains cottonwood (*Populus deltoides* Marsh.) within the 21st century (Pearce and Smith 2001; Lesica and Miles 1999). As a N_2-fixing species, Russian olive potentially functions as a so-called 'transformer' invasive species (D'Antonio et al. 2004) due to its ability to alter both terrestrial and benthic nutrient and community dynamics in invaded riparian areas (Mineau et al. 2012, -2011; Shah et al. 2010; Reynolds and Cooper 2010). Indirect effects of Russian olive, such as the intensification of beaver attack on increasingly reduced stands of native tree species, can alter riparian vegetation community structure and composition (Lesica and Miles 2004).

Few native tree species survive and thrive as well as Russian olive under the harsh growing conditions of the northern Great Plains (Stannard et al. 2002). In this geographical region, Russian olive is commonly viewed as a highly desirable and beneficial tree, and seldom considered to be an invasive noxious weed. Even so, negative impacts on Montana agricultural production necessitated the investment of more than $600,000 in Russian olive control projects between 2005 and 2007 (Montana Audubon 2010). As an example of polarization of attitudes toward Russian olive, on August 2, 2009 the *Billings Gazette* ran two articles under the headlines: "State asked to balance benefits, drawbacks of Russian olives," and, "A weed or wonder? Non-native Russian olive trees a nuisance to some, saviour to others" (http://billingsgazette.com/news/state-and-regional/montana/state-asked-to-balance-benefits-drawbacks-of-russian-olives/article_005cf908-7f0b-11de-bffe-001cc4c03286.html).

Conflicts of interest associated with the proposed regulation of non-native plant species are not unique to Russian olive (Stanley and Fowler 2004; Turner 1985). Benefits vs. costs of woody invaders such as acacia (*Acacia* spp.) (Dodet and Collet 2012; de Wit et al. 2001; Higgins et al. 1997) and tamarisk (*Tamarix* spp.) (Dudley and Bean 2012) continue to be hotly debated. Research conducted to develop management recommendations for invasive weeds is costly. Therefore, it is essential to determine early on whether the intended management target is viable in terms of stakeholders' perceived need for development of species-specific control methods, including classical biological control (de Wit et al. 2001; Higgins et al. 1997). A lack of communication among groups involved in or affected by weed management programs may lead to conflicts of interest and mistrust (Kapler et al. 2012; Wilson et al. 2011).

Classical biological control can be a sustainable, long-term approach for managing well established, widely distributed exotic invasive weeds such as Russian olive (McFadyen 1998). High selectivity and low risk of nontarget impacts further recommend biological control in ecologically sensitive and regulatory challenging riparian areas where Russian olive typically occurs. However, the movement and impact of biological control agents does not end at political or habitat boundaries, making their release unconstrained except by environmental and ecological restrictions, and therefore practicably irreversible. As an example, agents applauded for effectively controlling Russian olives clogging irrigation canals and bottomland pastures would not be welcomed to attack shelterbelt or ornamental trees. Any management program against Russian olive, including biological control, should therefore consider potential conflicts of interests of Russian olive as both an invasive and a beneficial species.

Foreign exploration and preliminary overseas screening of candidate agents for the present Russian olive biological control program, initiated in 2007, is being led by CABI Europe-Switzerland under the direction of the International Consortium for Biological Control of Russian Olive. Start-up funding provided by the Consortium's continually growing U.S. and Canadian membership has been used by CABI-

Europe to conduct literature and field surveys for potential biological control agents in the weed's native range, to experimentally increase knowledge about potential agents' basic biology and ecology, to conduct preliminary impact and host specificity assessments, and from those results, to produce a priority list of candidate agents (Schaffner et al. 2012).
Based on field surveys conducted between 2007 and 2015, and information obtained from taxonomists and through associated literature, a number of biological control candidates have been prioritized for live collection and in-depth studies. The search for candidate agents has deliberately focused on herbivores that impede the unchecked reproduction of Russian olive by disrupting the normal development of the fruit, shoots and flowers. This tactic was adopted to intentionally protect valued existing trees while holding the spread of unmanaged Russian olive plants in check. As a precedent, selection of site-specific (e.g., seed feeders vs. root feeders), non-lethal biological control agents was proposed as a viable compromise between management and stakeholder needs (or demands) for resources provided by black wattle (*Acacia* sp.; de Wit et al. 2001).

Perhaps more importantly, though, understanding and responding strategically to stakeholder concerns regarding planned biological control of Russian olive would significantly increase the feasibility and success of a future biocontrol program.

One activity conducted on behalf of the international Russian olive biological control consortium was to send out an electronic survey to solicit stakeholder and researcher feedback about Russian olive as a noxious weed and/or beneficial tree, desires to manage or conserve this tree, concerns about using biocontrol as a tool to manage Russian olive, other research concerns/gaps that need to be addressed prior to Russian olive management (esp. by classical biocontrol agents), and whether individuals would be interested in attending a conference to discuss aspects of Russian olive as a conflict species and whether biocontrol is a viable management option. The survey proved to be a useful starting point to assess stakeholder feedback about Russian olive and biocontrol, and to initiate dialogue during a USDA NIFA AFRI sponsored symposium held February 10-11, 2013 in Spokane, WA.

RESULTS

Respondent demographics:

The survey was completed by respondents located in the following Canadian province and U.S. states (n=392; number of respondents following province/state name): Alberta (Canada) – 1; Arizona – 7; Arizona, New Mexico and Utah – 1; California – 1; Colorado – 67; Colorado, New Mexico, Utah – 1; Idaho – 18; Illinois – 2; Kansas – 4; Maryland – 1; Missouri – 2; Montana – 173; Montana and Wyoming – 1; 'national' – 1; North Dakota – 4; Nebraska – 3; New Mexico – 7; New Mexico and Louisiana – 1; Nevada – 6; Oklahoma – 3; Oregon – 8; Pennsylvania – 1; South Dakota – 8; Texas – 1; Utah – 35; Washington – 4; Wisconsin – 1; West Virginia – 1; Wyoming – 27; and Wyoming, Montana, South Dakota and North Dakota - 1. Respondents self-identified according to non-mutually exclusive stakeholder categories (*n*=405) most frequently as 'federal government' (31.4%), followed by 'landowner' (25.4%), 'state government' (22.5%), 'county government' (22.5%), 'other' (12.4%), 'non-profit agency' (8.6%), 'college/university' (7.9%), 'town government' (3.2%), 'industry' (2.7%), and 'Native American tribe' (2.7%). Respondents provided the name and location of their group, agency or organization (not listed here), and indicated (*n*=371) that the activity or activities their group performed fell into the following broad, non-mutually exclusive categories: 'land management' (84.6%), 'education' (62.5%), 'research' (32.3%), fundraising' (9.2%), 'lobbying' (5.4%), 'hunting' (20.2%), or 'other' (19.9%). The region of interest of the respondents' group, agency or organization was county - 30.5%; statewide -22. 6%; specified area within a state - 19.8%; region within the U.S. - 18.8%; national - 4.9%; tribal lands - 1.9%; and city - 1.6%.

Respondents' perceptions of Russian olive as a weedy and/or beneficial plant:

Russian olive was believed by survey respondents to have escaped cultivation at the city/town scale by 67.6%, and at county or state scales by 85.4% and 94.4%, respectively. Russian olive was considered to be an invasive plant by 73.1% of respondents (*n*=379) at regional - 40.9%, state - 40.2%, county - 35.9% and/or town - 10.7% geographic scales. Respondents considered the following habitats to be negatively affected by the presence of Russian olive: riparian - 65.2%, wetland - 10.1%, pasture/rangeland - 9.4%, waterways - 6.5%, uplands - 5.4%, meadows/old fields - 5.1%, all habitats - 4.4%, and irrigated fields - 4.0%. The severity of Russian olive invasions was categorized by respondents (*n*=300) as high - 31.3%, medium - 45.7%, low - 18.0%, none - 2.0%, and don't know - 3.0%. Respondents described Russian olive as an invasive species according to its negative impacts on the following broad categories (limited here to the ten categories receiving the highest number of responses): native plants - 62.8%; habitat – 21.5%; water - 17.1%; wildlife - 14.8%; agriculture - 13.8%; access – 12.8%; none – 11.1%; hydrological – 8.1%; infrastructure – 5.4%; and recreation – 5.0%. Negative cultural impacts due to Russian olive as an invasive species were identified by only 3 respondents, which could easily cause the importance of access to and use of cultural sites and resources to be under-estimated if a numerical assessment of responses only was being considered.

Russian olive was overall considered to be a beneficial species by 52.8% of respondents (*n*=371) at regional – 27.4% (vs. invasive at 40.9%); state – 25.9% (vs. invasive at 40.2%); county – 41.1% (vs. invasive at 35.9%); and town – 12.2% (vs. invasive at 10.7%) geographic scales. Respondents considered the following habitats to be benefited by the presence of Russian olive: uplands – 31.5% (vs. harmed at 5.4%), riparian – 24.4% (vs. harmed at 65.2%), shelterbelts – 20.8%, dryland – 13.7%, windbreaks – 9.6%, ornamental – 8.1%, wildlife – 8.6%, and pasture/rangeland – 5.1% (vs. harmed at 9.4%). Respondents who considered Russian olive to be a beneficial species in their area ranked the usefulness of Russian olive benefits (*n*=224) as high - 39.3%, medium - 36.6%, low - 15.6%, none - 6.3%, and don't know - 2.2%. Write-in responses listed positive impacts due to Russian olive as a beneficial species in the following broad categories (limited here to the ten categories receiving the highest number of responses): bird/wildlife habitat – 72.4%; wildlife food – 46.9%; wildlife shelter/cover – 44.9%; shade/windbreak/shelterbelt – 42.1%; bird food – 40.2%; bird shelter/cover – 30.7%; ornamental – 20.5%; erosion control/bank stability – 16.5%; livestock shelter/cover – 9.4%; and none – 4.3%. Notable Russian olive benefits identified by respondents included nitrogen fixer (1.2%); nectar/pollen/honey (0.8%); carbon storage (0.4%); medicinal (0.4%); and discourages transient camps (0.4%). Respondents ranked the importance of the positive impacts of Russian olive (values for importance of negative impacts by rank provided for comparison) as high - 33.5% (vs. 46.5%); medium – 30.9% (vs. 29.7%); low – 22.8% (vs. 14.1%); none – 10.3% (vs. 6.0%); and don't know – 2.6% (vs. 3.6%).

Respondents' concerns about existing management options for Russian olive:

Write-in responses to the question, "what concerns do you have regarding existing management options for Russian olive control" were broadly categorized as cost – 23.0%; no consensus on the need for control – 21.7%; negative habitat impacts (of control methods) – 15.1%; none (no concerns) – 12.6%; unsustainable – 10.4%; approach/methods of control – 10.1%; lack of coordination of control programs – 9.4%; labor – 7.9%; efficacy – 7.2%; and spread - 5.7%.

Respondents' concerns regarding biological control of Russian olive:

With regard to biological control of Russian olive, 52.8% of respondents indicated that they had concerns, 33.4% were not concerned and 13.8% did not know if they were or should be concerned. Write-in responses addressing concerns about a defoliating biocontrol agent included potential for nontarget impacts - 42.7%; control not selective (would target both invasive and desired Russian olive trees) - 16.6%; potential negative impacts on wildlife/birds - 12.3%; agent, efficacy unpredictable - 11.4%; unwanted attack on shelterbelts/windbreaks - 10.4%; negative ecosystem impacts - 5.7%; generation and issues about the disposal of woody debris - 5.2%; feeling of being forced to control Russian olive - 3.8%; unwanted attack on ornamentals - 2.4%; and waste of money - 1.9%.

The top ten write-in responses regarding respondents' concerns about the use of a biocontrol agent that could actually kill Russian olive trees included many of the same categories: potential for nontarget impacts - 30.8%; control not selective - 18.2%; negative impacts on shelterbelts/windbreaks - 9.6%; deleterious effects on wildlife/birds - 9.1%; woody debris – 9.1%; none – 6.1%; potential to increase or encourage other invasive weed species – 3.5%; feeling that control was not needed – 3.5%; and potential for unacceptable harm to ornamental Russian olive trees – 2.5%.

Top five concerns about the use of a fruit/seed targeting biocontrol agent were: potential for nontarget impacts - 33.9%; none (no concerns over the use of a fruit feeder) - 27.4%; negative impacts of wildlife /birds - 20.2%; concerns that the agent or its efficacy will be unpredictable or inadequate - 11.3%; and concerns about control not being selective in terms of trees attacked (e.g., invasive vs. ornamental Russian olive) - 5.4%. Many write-in responses focused on the lack of information on the nutritional value and overall importance of Russian olive fruits for organisms at multiple trophic levels: arthropods, birds, and small vertebrates to large ungulate mammalian wildlife. One respondent suggested that stand replacement testing should take place to determine if species replacing Russian olive under natural succession following successful biological control would be acceptable or not as a food source for wildlife species now considered dependent on Russian olive fruits.

Respondents wrote in a number of other concerns about biological control of Russian olive and its potential impacts. The greatest number of responses (39.5%) specified concerns about potential non-target impacts. The next highest concern (16.0% of respondents) was about making biological control of Russian olive more selective in terms of the location of treatments, specifically, how to ensure that agents would be retained on stands of invasive trees targeted for control in riparian areas, reservoirs and irrigation ditches, and not randomly moving into upland bird habitat, ornamental or shelterbelt trees. Concerns about biocontrol impacts on bird and wildlife habitat quality, and potential issues with vegetation restoration and succession following biocontrol of Russian olive were cited at the same level, 8.3%. 15.3% of respondents had no concerns about potential impacts of biological control, while 10.6% felt that biological control options simply were not needed. One respondent felt that biological control of Russian olive should be studied in concert with saltcedar biocontrol. Another reported that in his/her experience, biocontrol agents tended to work best in upland sites, where Russian olive is considered an effective habitat component, but pointed out that biocontrol would be most valuable if it targeted trees invading moist habitats/shaded environments. One respondent, perhaps annually besieged by box elder bugs, voiced a legitimate concern that the Russian olive agents might also move to structures (houses) to over-winter. One respondent addressed in detail the potential economic impacts a Russian olive biological control program might have on upland game bird production and survival:

> "Please consider the economic impact to upland game bird production and survival. Hunters spend millions of dollars annually in pursuit of upland game birds in Montana. The Plentywood area in northeastern Montana lacks quality winter cover. Periodic severe winter conditions, in a region lacking quality winter cover, suffer high mortality losses. Local restaurants, gas stations and

motels experience the loss of revenue generated by reduced hunter traffic following tough winters. We have significant documentation to show high pheasant and sharptailed grouse survival rates in locales containing Russian olive thickets or shelterbelts containing Russian olive."

Respondents' suggestions for additional research:

Respondents were asked to write in suggestions for additional research 1) needed on biological control of Russian olive, such as studies on wildlife impacts, consequences of fruit reduction, possible impacts on endangered species, etc.; 2) to better understand Russian olive in their area, or nation-wide; and 3) any other research suggestions related to Russian olive.

In response to the question "Can you suggest any additional research needed on biocontrol of Russian olive, such as studies on wildlife impacts, consequences of fruit reduction, possible impacts on endangered species, etc.?", 67.6% of respondents indicated that additional research was needed but not all specified the type of information they felt was lacking or unavailable. 23.7% of respondents indicated that no further research was required; 1.7% did not know if information was lacking; and 4.0% were opposed to all aspects of Russian olive biological control, including further research (n=173). Few of the write-in responses to this survey question actually suggested studies that would clarify issues directly related to biological control. Most instead indicated a critical need to better understand and assess the value of Russian olive's ecological and economic contributions to western and southwestern shrubland.

The majority of suggestions for additional research on biocontrol of Russian olive addressed concerns about the value of Russian olive as a resource for wildlife (36.4%). Respondents wanted to know which wildlife species currently utilize Russian olive, which species have become dependent on the resources it provides, and why species have become dependent on resources provided by this relatively recent invader. Multiple respondents prioritized the need for quantitative documentation on the quality of basic wildlife resources, such as food and shelter, provided by Russian olive. Data gaps identified included nutritional and energetic analyses of Russian olive's overall contribution to the diets of resident and migratory wildlife, and specifically to stored fat reserves essential to successful migration or over-wintering; percentage of game (bird and animal) foraging conducted in Russian olive stands, broken down by season; and dependence of game and livestock on Russian olive for fawning/calving cover. The possibility that Russian olive was driving and therefore probably altering avian and other species distributions was raised.

215 respondents wrote in answers to the question "Can you suggest any research which needs to be conducted to better understand Russian olive in your area or nation-wide?"; 'no' was the most frequent response (19.1%). The second most frequent category of response addressed the need to better understand the type and quality of resources provided by Russian olive to livestock and wildlife, including birds (18.6%). Objective comparisons of nutrition and shelter provided by Russian olive vs. native tree or shrub species were specifically requested, as in this example: "I would like to know the wildlife preferences in associations of hawthorne and silver buffaloberry in shallow water table areas". Another respondent wanted to know if variability in other ecosystem attributes was driving localized increases or decreases in wildlife utilization of Russian olive: "Is there a difference between wildlife utilization of (Russian olive) depending on what area of the country? For example, in areas where resources are more limited, is (Russian olive) acting more 'beneficial?'".

Risk: benefit or cost: benefit analyses as a way to objectively weigh the ecological or economic costs against the benefits of Russian olive control or removal were suggested by 9.8% of respondents. 8.8% of responses addressed the need for further research to better understand how Russian olive infestations impact floral and faunal biodiversity. 8.4% of responses called for further research to identify factors predictive of Russian olive infestation. Many respondents had specific questions about succession or restoration of the vegetation community following Russian olive control or removal (7.9%). The same percentage of responses (7.9%) addressed the need for additional research on the distribution and spread of Russian olive. 6.5% of responses suggested that additional research was required to understand how to selectively target biocontrol to areas where Russian olive is considered invasive, and that further unspecified biocontrol-related research was required. Four categories of further research were suggested in the same percentage of responses (5.6%): general impacts of Russian olive infestations; Russian olive biology/ecology; breeding programs to produce sterile or non-invasive Russian olive or suggestions for alternative plants for ornamentals, shelterbelts and bird/wildlife food and habitat; and improving conventional or integrated control of Russian olive.

Write-in responses for other research suggestions related to Russian olive (n=124) listed 'no' as the most frequent response (43.5%). Ecological studies to assess both positive and negative impacts of Russian olive were listed as the second most frequent broad category of suggestions for further research (14.5%). Suggestions for additional ecological research focused on water use and hydrological themes would investigate the potential for Russian olive to lower the water table and thereby help control saline seep; Russian olive water uptake potential and how it can alter hydrology; assessing water use by Russian olive in riparian areas and impacts Russian olive water use has on other species and on creek flow; comparing river management (stage height level and duration) to Russian olive establishment levels; timeline of watershed infestation by Russian olive; and how flooding inundation affects Russian olive, and duration of inundation required to impact Russian olive. Suggestions for additional ecological research on vegetation and soil focused topics included the potential use of beneficial trees or shrubs to crowd out Russian olive; community interactions among plant guilds and how they might be affected by allelopathic root exudates of Russian olive; determine the level to which Russian olive (soil) bacterial symbionts fix atmospheric nitrogen in the native and invaded range; changes in soil and water temperatures, aquatic invertebrate as well as vertebrate populations around Russian olive stands; influence of Russian olive on changes in soil pH; and length of time required for dead standing trees to decay.

Additional research on alternatives to Russian olive was suggested by 10.5% of respondents, and included identifying native plant alternatives, or developing sterile or fruitless varieties Russian olive, and less invasive or sterile hybrids of Russian olive, such as the Silverscape® olive (hybrids of Russian olive and silverberry). One respondent suggested research to identify a Russian olive variety that was more palatable to beavers, then using it to cross-breed into zones where invasive varieties currently dominate so beavers could be used as biological control agents. A related but significantly more ambitious research suggestion involved breeding a special strain of beavers "that will eat the stuff".

Responses suggesting studies broadly concerned with better understanding the post-removal environment (7.3%) included research to assess post-removal changes in flora and faunal biodiversity; changes in soil structure and/or nutrient load occur where Russian olive formed monocultures, and these might impede re-vegetation efforts; (a priori) establishment of funding, policies and implementation plans to ensure re-vegetation with native plants to counteract reductions in fruit/pollen resources following Russian olive removal; potential widespread impacts on stream bank stabilization following large scale Russian olive removal; determining how quickly native species respond to Russian olive removal from riparian habitats; and possible uses of and options for dealing with Russian olive biomass generated through removal or control efforts.

6.5% of respondents suggested additional research focused on developing recommendations for Russian olive control or management recommendations, including: suggestions for reasonable (levels of) control rather than eradication; developing recommendations for buffers around riparian areas to prevent invasion of Russian olive from upland shelter belts, to preserve shelter belts and prioritize areas for control or eradication; options for mechanical control; (comparison of) successes of different methods of Russian olive control; development of selective herbicides – "investing in research and development of herbicides that are species specific"; "what can be done to prevent the spread of the tree"; developing innovative management prescriptions such as using a root-collar damaging technique that works well without pesticide; "attack the root system to reduce seed production by lowering the plant vigor"; methods to reduce/eliminate Russian olive stands where it has become invasive; timing of mechanical cutting, possibly in conjunction with a herbicide treatment; and developing best management practices for Russian olive removal.

SUMMARY

Survey responses uniquely confirmed in the respondents' own words how readily conflict arises when plans to control Russian olive are discussed. Benefits of Russian olive provided to those who dwell and farm or ranch on the northern Great Plains, in terms of upland shelterbelts, erosion control and shade or ornamental trees, are indisputable. However, in riparian areas, wetlands and irrigation canals where it not moisture-limited, Russian olive can become highly invasive and competitive, displacing desirable native species and often forming impenetrable, persistent monocultures.

Dense infestations of Russian olive in moist habitats incur unacceptable losses of both surface and sub-surface water and block access to valuable streamside habitat, watering and recreational sites for native or desirable plant species (e.g., cottonwood), livestock, wildlife and people. Forfeited environmental resources combined with the exorbitant cost of conventional control suggested that a management approach focused on stemming the unchecked reproduction and spread of Russian olive without harming valued upland trees would provide an acceptable compromise. However, survey responses indicated that all forms of biological control presented some level of threat to upland ornamental, shade and shelterbelt trees due to the agents' unrestricted movement.

Respondents suggested that more information was needed on potential impacts to wildlife under various outcomes of Russian olive biological control. Although no conclusive data currently exists on the nutritional value of Russian olive drupes ('olives' or fruits) to wildlife, survey write-in responses conveyed a nearly universal belief that the fruits are a valuable and important food resource for game birds and animals. Respondents were reticent to give unqualified support to biocontrol specifically targeting Russian olive fruits. Numerous suggestions were made about the possibility of using selective breeding to produce trees with infertile drupes in order to reduce invasiveness while retaining fruit production benefits for wildlife.

Projecting into a future where biological or other control may cause Russian olive to become locally or regionally extirpated, respondents identified two critical needs, to fully understand 1) how to facilitate the successful establishment of native alternatives to Russian olive, and 2) the nutritional value, accessibility and preferences of wildlife and livestock for fruits born by native plants as compared to those provided by Russian olive. Respondents sought assurances that native plant species or sterile varieties of Russian olive could reliably provide the same key resources to wildlife currently supplied by invasive, fertile-fruited Russian olive (equivalent host suitability). Respondents were concerned about how readily species adapted to using Russian olive resources could or would successfully switch to obtaining food and shelter from alternative hosts (equivalent host acceptance). A study to compare the number and variety of wildlife species using similar habitats with, and without Russian olive was suggested to identify important indirect interactions following removal.

Specific concerns were conveyed about potential deleterious impacts of Russian olive removal from riparian/wetland areas inhabited by endangered species such as yellow-billed cuckoo or southwestern willow flycatcher. Respondents questioned whether species relying on Russian olive as a sub-canopy layer for foraging habitat would return to treated areas once native riparian shrubs and trees re-established. Support and maintenance of wildlife, including birds, in areas targeted for Russian olive control was directly linked by many respondents to successful restoration. The importance of planning and research to develop practical restoration recommendations was repeatedly emphasized.

Respondents' greatest concern about Russian olive biological control was the perceived potential for non-target impacts, highest for defoliating agents (42.7% of respondents), followed by agents that could kill whole trees (38.8%), then fruit/seed reducers (33.9%). These responses reflect a prevailing misconception about weed biological control agents: that their behavior is unpredictable, particularly in response to a scarcity or lack of host plants, putting non-targets such as ornamental and crop plants at high risk of attack (Delfosse 2005; Pemberton 2004; Hoddle 2003).

Additional research and outreach could address the majority of concerns and sources of conflict identified through this survey. These efforts should begin by dispelling the most pervasive misconception about weed biological control, that the risk of non-target attack is very high. The results of a recent meta-analysis of intentionally introduced weed biological control agents found that globally, >99% of agents released have had no known significant adverse impacts on non-target plants (Suckling and Sforza 2014).

Pesticides and baits, proven effective respectively for excluding or concentrating biological control agents in other agent-weed systems, could be used to protect upland trees and focus attack on invasive bottomland stands of Russian olive. Feeding studies to assess the nutritional value of Russian olive for game birds and animals would objectively confirm or refute claims that it is an essential high quality food source. Considerable additional research will be required to assess the quality of wildlife resources provided by native alternatives to Russian olive, once protocols for successful restoration have been identified. Overall, prospects for biological control of Russian olive are positive because research and outreach can realistically address concerns disclosed through this survey.

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Using Search Dogs for Biological Eradication Programs – A Tale about Dyer's Woad (*Isatis tinctoria* L.)

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ABSTRACT

Dyer's woad (*Isatis tinctoria* L.) is listed as a noxious weed in Montana, and eradication is the management goal in this state. Eradication requires nearly-perfect detection of individuals in a population, which is frequently infeasible, particularly in complex environments. Diligent monitoring and treatment of Mount Sentinel, which is home of the only known population of dyer's woad in Missoula County, MT, has reduced the population dramatically. However, locating the remaining plants has proven onerous on this steep and shrubby mountainside. We trained three detection dogs to locate dyer's woad by scent, and deployed them for four seasons of management activity. After the fourth year of dog involvement, the Mount Sentinel population is decreased by 99% from its peak, with just 20 plants located in season four. Furthermore, the dog teams located nearly 42% of plants that had been previously overlooked by human surveyors, and found more than twice as many unique locations harboring dyer's woad plants. We contend that dogs aid weed control efforts by improving detection of low density targets, which may result in an expedited eradication process.

Keywords; Detection, invasive, weed management, canine, conservation, dyer's woad, noxious, plant, dog, eradication, EDRR

INTRODUCTION

Dyer's woad (*Isatis tinctoria* L.) is native to southeastern Russia and was introduced to the United States in the early 1900s (Callihan et al. 1984). It is a short-lived perennial of the mustard family (Brassicaceae) that thrives on disturbed sites but plants also establish on undisturbed rangeland and open forest habitat types. It is a prolific seeder, averaging 400 seeds per plant per year (Zouhar 2009) with reports up to 10,000 seeds per plant (McConnell et al. 1999).

Dyer's woad is listed as a noxious weed in 11 states (AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA, WY) (USDA NRCS 2015). It was first detected in Montana in 1934, and has been reported in 17 counties. In Montana, the plant is listed as a Priority 1A noxious weed, a designation that requires eradication.

Dyer's wood is managed for eradication under the Montana Dyer's Woad Cooperative Project, as overseen by the Dyer's Woad Task Force (contact aburch@beaverheadcounty.org), with the goal of eliminating dyer's woad from Montana.

During this project, dyer's woad was active in seven counties. An active site is monitored for yer's woad plants until the site has gone eight years without a dyer's woad plant being found; at that point the site is deemed eradicated by the Dyer's Woad Task Force. One such site occurs in Missoula County on Mount Sentinel, located adjacent to the University of Montana's main campus. This infestation was detected in the early 1990s. Since then, sustained regular efforts have focused on finding and removing every plant. The population has been greatly reduced, but not eradicated. Eradication depends on high detection rates and near-perfect control for many years (Tomley and Panetta 2002). Missed plants that reproduce can extend the longevity of the seed bank and increase the time required for eradication.

As management has reduced the population density on Mount Sentinel, detection of individual plants has become increasingly difficult. This site is steep and has many thickets of dense shrubs, resulting in difficult search efforts. Higher operational costs are often associated with these later stages of control efforts.

Humans rely on visual cues to find plants, while dogs use olfaction to find targets. Compared with human vision, canine olfaction is less affected by noise (i.e. background interference) due to the hundreds of different receptor types that converge to amplify the incoming signal while reducing input noise (Buck & Axel 1991; Vassar et al. 1994). The ability to increase signal to noise ratios and thoroughly search large areas might explain why the success rate of search dogs was almost twice that of human surveyors (67% vs. 34%) for small, obscure spotted knapweed (*Centaurea stoebe)* plants (Goodwin et al. 2010).

Conservation detection dogs—those specializing in locating biological targets of interest to managers—have been used to assist field biologists and conservationists for over 100 years (Hurt & Smith 2009; Woollett et al. 2014). Dogs have been trained to find targets such as feces, nests and dens, live and dead animals (birds, invertebrates, and reptiles) and plants (see MacKay et al. 2008; Hurt & Smith 2009; Woollett et al. 2014). Dogs can reduce the time required to find a plant of interest (Browne & Stafford 2003), correctly scent-discriminate between plant species (Sargisson et al. 2010), locate rare plants in a field setting with high degree of accuracy (Goodwin et al. 2010; Vesely 2008), and find individual plants with greater accuracy and from a greater distance than human surveyors (Goodwin et al. 2010).

We used search dogs to find dyer's woad plants at low densities on Mount Sentinel in 2011, 2012, 2013, and 2014. Our goal was to determine if search dogs could improve detection of dyer's woad on this site. Our objectives were to:

- Determine if dogs could detect dyer's woad by scent, and distinguish it from other plant species in field settings;
- Assess if search dogs provide a detection advantage over human surveyors; and,
- Help meet the goals of the Montana Dyer's Woad Cooperative Project to support eradication efforts

To our knowledge, this project represents the first time detection dogs have been systematically used to help land managers eradicate a nonnative plant species.

MATERIALS AND METHODS

2.1 Study Site
Mount Sentinel is located on the eastern edge of the city of Missoula in Missoula County, Montana. Eradication efforts have been ongoing on approximately 81 ha since 1999. In 2005, the dyer's woad population peaked at 2,673 plants. The site is dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*) and rough fescue (*Festuca scabrella*) grassland, with scatted deciduous shrubs including chokecherry (*Prunus virginiana*), serviceberry (*Amelanchier alnifolia*), and ninebark (*Physocarpus malvaceous*). The weed population is located on the western face of Mount Sentinel, a steep west-facing slope that receives heavy recreational foot traffic. Average annual precipitation is 340 mm. We sectioned the site into 23 search zones, which were delineated based on trails or terrain features such as gullies (see Fig. 1).

2.2 Dog Training
Dyer's woad plants and native plant species known to occur on Mount Sentinel were grown from seed in pots under a greenhouse setting. Once the dyer's woad plants reached approximately eight cm in height and developed six or more leaves, we used them as odor source material for dog training. In 2011, three dogs were trained to detect dyer's woad by scent (see Table 1). One additional dog was trained in 2013

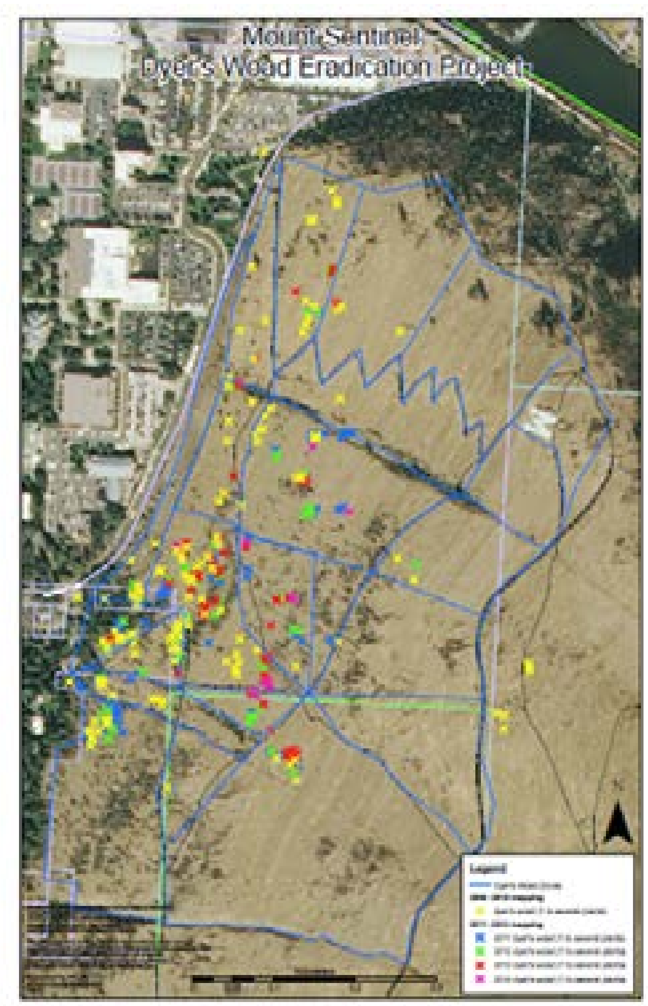

Figure 1. Dyer's woad locations on Mount Sentinel 2004-2014. Blue lines indicated the designated search zones.

using similar methods and dyer's woad plant material that was dug from the field site. All dogs were experienced with scent training and field deployment.

The dogs were trained to associate the scent of dyer's woad with a receiving a play or a food reward after giving an alert to their handler that they found a plant, as described in Goodwin et al. (2010) and Vesely (2008). The alerts were trained behaviors—either a sit, a down, or standing and barking near the plant, whichever was best suited to the dog's preferred mode of communication. Search training was conducted on Mount Sentinel with naturally occurring plants or on field sites using fresh-cut dyer's woad material (for training details see Goodwin et al. 2010, Vesely 2008).

Search training progressed based on performance benchmarks; dogs were deemed ready to progress to the next stage of training when they performed the alert consistently and over each iteration without prompting from the handler, and without incorrectly alerting to a non-target plant. Handlers worked the dogs both on- and off-leash.

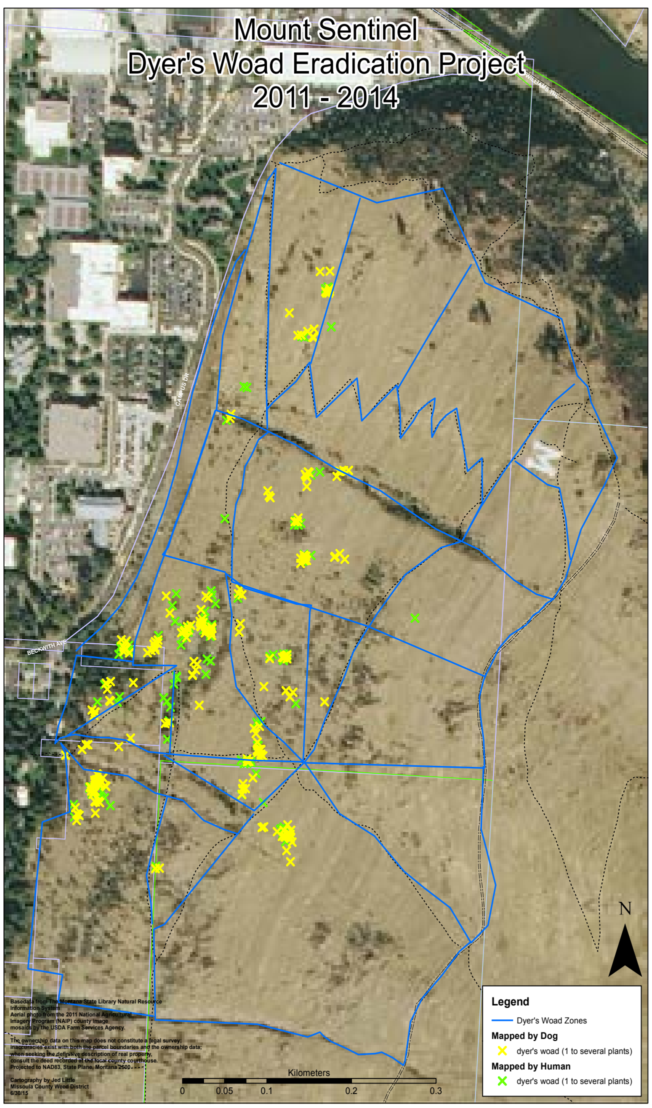

Figure 2. Dyer's woad 2011-2014, by Human surveyor and by dog teams.

2.3 Field Deployment

The prevailing dyer's woad monitoring and control activities were implemented on Mount Sentinel during this project. More specifically, one human surveyor searched for and controlled plants during the growing season for approximately eight hours per week. The first year, plants were removed via digging; in subsequent years the herbicide Cimarron® (DuPont™, Wilmington, Delaware) was applied to the soil as a spot treatment after removing as much of the plant as possible through digging. The surveyor also recorded the location via GPS, the number of plants and age class. Community "woad pull" events were also held each year in which volunteers walked abreast in a line five to ten m apart looking for and removing plants.

2.3.1 Year 1 (2011 June 1 to Oct 25)

We deployed two dog teams (Dogs 1 and 2, see Table 1) consisting of one dog, one handler, and occasionally one assistant who helped navigate, record data, and treat plants. The primary responsibility of the handlers was to interpret dog behavior, but they also located some plants opportunistically. Dog teams searched approximately nine hours per week during five days each week. Handlers directed the dogs—or the accompanying assistant directed the dog team—along parallel search transects at five to ten m intervals. The surveyor and dog teams searched the zones independent of each other. Each dog team (Dogs 1 and 2) covered different search zones such that the combined searches created one search of the 23 search zones. The handler maintained an active track log on a GPS to record where the dog team had searched (logging a location every 20 seconds in NAD83 datum).

Table 1. Dogs trained for dyer's woad detection.

Dog	Age when trained to dyer's woad	Breed	When deployed	Previous years detection experience	Previous type of detection experience
1- Seamus	2	Border collie	2011, 2012, 2013, 2014	0.5	Conservation
2- Wibaux	7	Labrador retriever	2011, 2012	6.5	Human remains detection, search and rescue, avalanche
3- Pepin	5	Belgian malinois	not	2	Conservation
4- Lily	5	Labrador retriever	2013	2	Conservation

When a dog alerted to a dyer's woad plant, the handler would confirm the target and then reward the dog. The handler recorded the location using GPS and the number of plants, the age class (rosette, flowering, or seeding), whether the dog or the handler located the plant first, and the approximate distance at which the plant was first detected. The handler then treated the plant. If the dog alerted to a specific area and the handler could not find a plant, the handler performed a minimally rewarding behavior called a "read and go," as described in Cablk and Harmon (2011), wherein the handler stroked the dog calmly as an acknowledgement of the alert, but without supplying the dog the toy or food reward.

2.3.2 Year 2 (2012 May 29 to Oct 31), Surveyor-then-Dog-Team Protocol

For Year 2, the surveyor searched and treated plants in a zone and then a dog team would search the same zone a mean of 17 days later to locate and treat any plants missed by the surveyor. Dog teams searched approximately eight hours per week during four days each week. Two surveyor-then-dog-team sweeps were performed. The first sweep covered the 23 zones and the second covered only the zones where plants had been located. Dog teams were not deployed for several weeks in August and September when field hazards were at their peak. These hazards included heavy wasp activity, senescing vegetation which undermined secure footing, and seeding cheatgrass (*Bromus tectorum*), which is easily lodged in dog ears, nose, tonsils, and eyes.

2.3.3 Year 3 (2013 May 22 to Oct 23)

The Year 2 protocol was followed with the following exceptions: one dog team (Dog 1) performed the searches and the surveyor recorded a search track log on the GPS. The surveyor searched approximately two days each week for four-and-one-half hours per week. The dog team searched approximately three-and-one-half times per week for seven-and-one-half hours per week. Dog team searches were conducted five days after the surveyor search, on average. This was done to ensure new plants did not emerge during the time between the surveyor and dog searches, as Pokorny and Krueger-Mangold (2007) report dyer's woad plants can grow up to ten cm in one week. Two surveyor-then-dog-team sweeps over the entire area were performed.

2.3.4 Year 4 (2014 May 14 to Oct 20)

One dog and handler team (Dog 1) conducted all the monitoring, and no surveyors were deployed. The team searched an average of two-and-three-quarters sessions a week for six-and-one-half hours per week. No searches were conducted in August, and only a final spot check was conducted in October.

2.4 Mapping and Data Analysis

Dyer's woad location data was recorded on a Garmin GPS (eTrex Vista HCX and Oregon, Garmin International, Inc., Olathe, Kansas), transferred to a computer, differentially corrected, and then exported as an ArcView (ESRI, Redlands, California) shapefile. Based on manufacturer specifications GPS units were assumed to be accurate within approximately three m. Maps were produced to display the locations of plants found by surveyors since 2004 and by dog teams 2011 and onward (Figs. 1 and 2).Only dyer's woad plants found using the surveyor-then-dog-team protocol were included in our analysis using descriptive and summary statistics. Additional plants found during other "human" activities, such as community woad pulls, repeat visits to sites to apply herbicide, training activities, and end of season checks, were not included in the analysis and are reported in the total plant counts (see Table 2, and Fig. 3). Detection accuracy of surveyors and dog teams was not calculated because ground truth, or the actual number of plants in the population, was not known.

RESULTS

3.1 Number and age class of dyer's woad plants

A total of 1272 plants were found during Years 1, 2, 3, and 4 by surveyors, dog teams, and other human activities. In Year 1, 600 plants were found; 388 of these plants were found by dog teams (see Table 2). Of the 600 plants, 5% were flowering and 2% were seeding. The dogs located rosettes, flowering, and seeding plants and one dog (Dog 2) located root fragments, which had remained in the soil from a previous hand pulling treatment. A total of 504 plants were found in Year 2, of which, 201 were located by dogs. In Year 2, dogs occasionally located plants that were present as roots with only a small amount of foliage (see Fig. 4). Sometimes weeks after a dog initially alerted to an area, the handler was finally able to see small rosettes present, despite seeing nothing at the time of the initial alert. Dog 2 also alerted to a cache of dyer's woad seeds in a rodent burrow.

In Year 3, 148 plants were found by surveyors and dogs and other people. Five plants (3%) were flowering and none were seeding. Dog teams found 57 plants and 91 plants were located by the surveyor, dyer's woad hand pulling project participants or by handlers treating plants without the dogs present. By excluding the plants found outside of the human-then-dog-team protocol, a total of 97 plants were included in our analysis with 58 plants located by surveyor and 39 plants located by dog teams.

Table 2. Detection Summary, 2011-2014

	Year 1 (2011)			Year 2 (2012)			Year 3 (2013)			Year 4 (2014)			4-year totals/average		
	Dog team	Surveyor/ human	Yr 1 total	Dog team	Surveyor/ human	Yr 2 total	Dog team	Surveyor/ human	Yr 3 total	Dog team	Surveyor/ human	Yr 4 total	Dog team	Surveyor/ human	Total
rosettes	365	189	554	198	294	492	55	88	143	19	0	19	637	571	1208
flowering	10	22	32	1	9	10	2	3	5	0	1	1	13	35	48
seeding	13	1	14	2	0	2	0	0	0	0	0	0	15	1	16
total plants	388	212	600	201	303	504	57	91	148	19	1	20	665	607	1272
# of plants found under comparative protocol	N/A	N/A	N/A	161	223	384	39	58	97	N/A	N/A	N/A	200	281	481
% plants not found by surveyor	N/A			41.9%			40.2%			N/A			41.6%		
% dog found before handler	66%			98%			80%			95%					

^ "humans" include volunteers during public weed pulls, handlers finding plants when no dog present (e. g. while spraying herbicide)

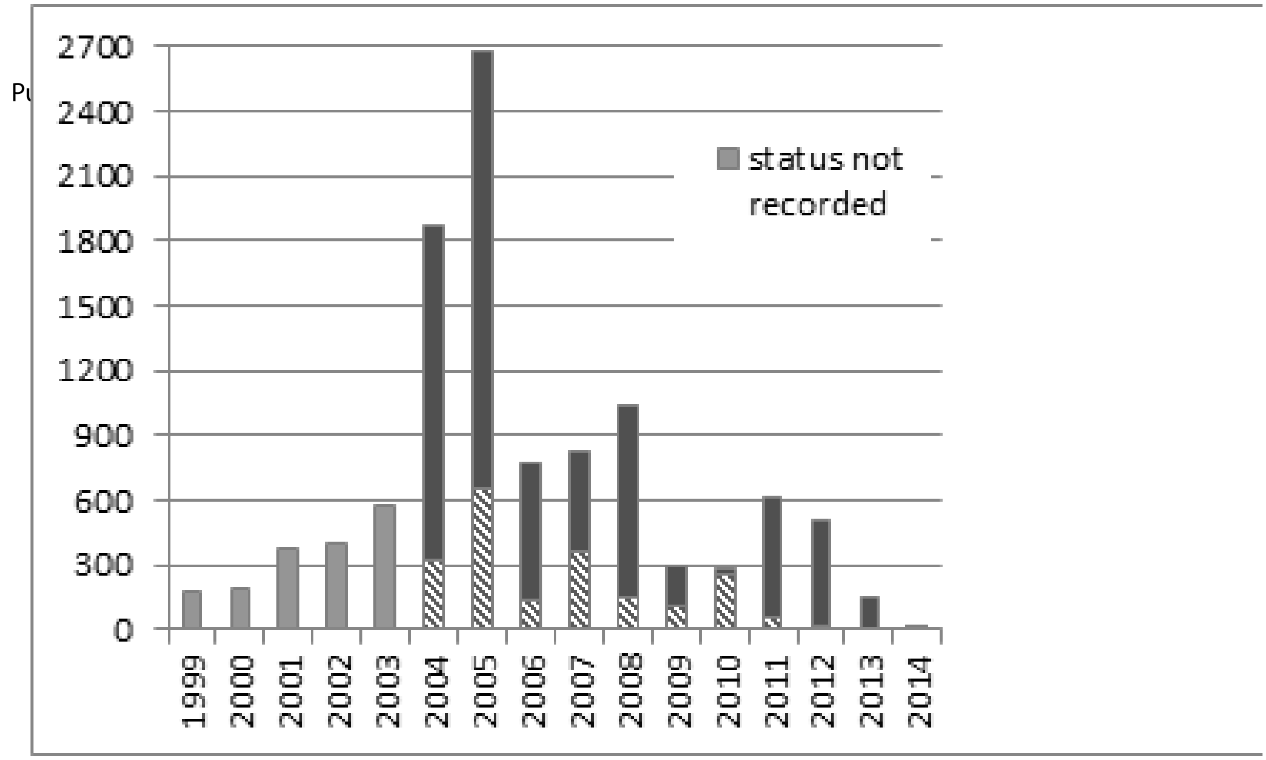

Figure 3. Dyer's woad located on Mount Sentinel, Missoula, MT, under Dyer's Woad Task Force's eradication initiative 1999-2014

Figure 4: Dyer's woad root fragment left in soil after plant removal and later detected by Dog 2. Arrows point to the minute foliage remaining on the root at time of detection, indicating resprouting. Photo: D.Tirmenstein

Figure 5. Dyer's woad plants range from emerging seedlings to flowering or seeding plants taller than the dog. Photos: Working Dogs for Conservation.

In Year 4, 20 plants were located. Nineteen plants were located by the dog team, and one was located opportunistically by weed control personnel while performing other activities on Mount Sentinel. Just one plant was flowering, the other 19 (95%) were rosettes.

Early in Year 1 while gaining experience, 49% of the plants were first detected by dogs and 36% by handlers. For the remaining 15%, it was not clear which party detected the plants first. Later in Year 1, dogs were first to find 85% of the plants in August and October and 97% of the plants in September. The remaining plants attributed to dog teams were located by the handlers. The dogs were first to locate 98%, 80%, and 95%of the dyer's woad plants during Years 2, 3, and 4, respectively.

3.2 Dyer's woad locations

Many plants found during Year 1 were located 25 to 50 m away from previously known locations (see Fig. 1). All plants found in Year 2 were located within 25 m of plants that were located in previous years. Four locations were found 25 m from previously known sites during Year 3, and all other plants were less than 15 m from previously known locations. All Year 4 plants were within 15m of previously identified plant locations.

3.3 Dog team performance

3.3.1 Plants missed by surveyor and found by dog teams

Of the 384 plants located by the surveyor and dog teams during the comparison protocol in Year 2, 41.9% (n = 161) were found by the dog team and potentially missed by the surveyor. The amount of time between surveyor and dog searches in Year 2 averaged 17 days (range 1-41 days). During Year 3, 40% of the plants were found by the dog team, and the time between surveyor and dog searches averaged five days.

3.3.2 Dogs detected more unique locations of plants than surveyors

We observed 41 distinct areas where one or more plants were located >12 m from the nearest dyer's woad plant. Dogs found 15 out of 41 (36%) of these unique locations. Although surveyors searched these areas first, they found only six (15%) unique locations that were not later also discovered by dog teams.

DISCUSSION

4.1 Dogs can detect dyer's woad plants across age classes and distinguish it from other plants

Our study demonstrates that dogs trained primarily with dyer's woad rosettes in pots can generalize the scent to recognize plants at other life stages. Plants were detected throughout the growing season as rosettes, flowering and seeding plants, as well as roots (see Figs 4 and 5). Detection distances, when observed (as determined by the handler noting the onset of dog behavior indicative of homing in on a target),were typically three m or less with a few occurrences up to 15 m. The plants did not appear to be more or less detectable to the dogs within different age classes. Dyer's woad detection dogs are capable of recognizing roots without foliage, and some dogs alerted to roots without specific training on root odor without foliage. We observed Dog 2 detect root material; this dog had previous experience at human remains detection, where targets are often buried, small, and lack above-ground material. We believe this experience led this dog and handler to be predisposed to finding buried roots, and would not expect that teams without such experience would find this variant of the target without explicit additional training on search strategies conducive to finding buried targets.

We did not observe dogs alerting to other plant species, but they occasionally alerted to a site where dyer's woad could not be found by the handler. They also alerted to holes that had been created while removing previously located plants. On four occasions, we observed Dog 2 alerting to a specific area without a visible target plant. Her handler dug at the locations and found root fragments, which most likely were causing the alert. On nine different occasions, we observed Dog 2 alert without any visible plants found by the handler and without attempts to locate roots. However, in this area rosettes were later found indicating that the dog was likely alerting on root material growing below the surface of the soil. There were numerous times when both dogs (1 and 2) alerted to holes where plants had previously been located and removed, even when the former plant had not been found by the dog, therefore the dog did not alert based on memory. Given that plant roots emit volatile organic compounds, we assume that the dogs were responding to the odor of the roots. Thus, dogs correctly identified the target plant as present in the absence of any visual cue observable to the handler.

Dogs may possess additional detection abilities not explored in this study. They have been shown to successfully detect up to 10 odors without a diminished ability to detect the previously trained odors as new ones are added (Williams and Johnston 2002). Given the ability to search for multiple targets, and the success of multiple target search dogs reported in other conservation detection dog projects (Long et al. 2007a, Vynne et al. 2011), we propose training dogs to find more than one plant species of interest simultaneously. For example, the authors have successfully located nonnative plants, Chinese bush clover (*Lespedeza cuneata*) and native plants, whorled milkweed (*Asclepias verticillata*); within the same search area during the same search session (Working Dogs for Conservation unpublished data). Dogs may be particularly useful when the target plants are inconspicuous, visually obscured, or similarly colored as the surrounding vegetation.

4.2 Dogs find plants that aren't found by surveyors

The primary aim of this study was the early detection and rapid response treatment of dyer's woad, thus plants were removed upon detection. This means that plants first found by surveyors could not later be found by dog teams. Because the dogs searched sites following the surveyor, we assume that plants found by dogs were overlooked by surveyors. During Years 2 and 3 of the study, the dog teams found 42% and 40% of plants, respectively, which were missed by surveyors, escaping control. These plants would most likely have reproduced and increased the soil seed bank. Our study showed that the use of search dogs can increase the probability that weeds can be detected and controlled at low densities. This is critical for early detection and rapid response efforts, decreases the time required to achieve local extinctions for weeds and ultimately reduces weed management costs.

4.3 Dogs locate plants before they become reproductive

During the seven years of dyer's woad monitoring solely by surveyors, and reproductive status data were collected, 14-92% of all plants located were flowering or seeding. Since dog team involvement an average of 5% of the plants found have been reproductive (7% in 2011, 2% in 2012, 3% in 2013, and 5% in 2014—which represents just one plant, as so few plants were located in 2014). More specifically, an average of just 1% of the plants located in these years were seeding; this meets the statewide dyer's woad management plan objective of 1% or less plants allowed to go to seed.

Furthermore, the eradication metric used is that a population is considered eradicated when no plants are located in an area in eight years. Since dogs in our study are finding more plants than surveyors and before they become reproductive, we anticipate achieving the eight-year free period sooner than if the monitoring were conducted solely by surveyors. This may result in early cessation of eradication activities, thus saving costs.

4.4 Cost considerations

Given the time and experience required to train dogs, in addition to the daily care of a detection dog, conservation detection dog teams tend to cost more than surveyors. Even so, in other studies, dogs have been found to cost more than alternative methods but be most cost effective due to their performance. Long et al. (2007b) compared detection dogs with camera traps and hair snare surveys in a carnivore study and found that dogs produced the highest number of overall detections, unique detections, and probability of detections, and as such, they were deemed the most cost effective of the methods despite having the highest base cost. Harrison

(2006) studied bobcats (*Lynx rufus*) using detection dogs and three other survey tools and reports that while dogs cost twice as much as the other methods, they produced ten times the detections of all the other methods combined.

Surveyor costs on Mount Sentinel were $3,000 to hire one surveyor for one growing season. For Year 4 (2014)—when dog teams were the only means of detection employed—the cost to hire a dog team for the season was $12,000, and since many of the 23 designated zones have never produced a single dyer's woad plant, search coverage has been streamlined and the anticipated cost for the 2015 season is $6,500. While this is more than double the cost of a single surveyor, the fact that surveyors in this study missed over 40% of the plants must be considered. Alexander et al. (2012) used groups of five surveyors to look for a plant (in this case a rare milkweed). The total number of plants located by the group of five was considered to be 100%. Smaller groups of three to four surveyors located 90-99% of these plants, but groups of one or two had extensive variation and detection rates as low as 40%. The authors note that two surveyors were always better than one. Applying these results to dyer's woad eradication on Mount Sentinel suggests that employing at least two surveyors would be warranted, which would make the annual cost $6,000 which is commensurate with the cost of the dog team. Moreover, as the dog teams will likely allow the dyer's woad population to be eradicated over fewer years, thus removing the need for site monitoring, the best measure of cost is not on an annual basis, but over the duration of the project.

CONCLUSIONS

- Dogs trained to detect a specific age class of a plant have the ability to generalize to other age classes and find them growing in natural conditions, which is advantageous if training plants are difficult to acquire, or the handling and transport of reproducing noxious weeds is problematic or prohibited

- Detection dogs can find individual invasive plants overlooked by human surveyors, and find more unique plant locations. Detection dogs benefit eradication program activities, namely early detection, detection at ever diminishing densities, and public education

- Due to early detection fewer plants will reproduce each year, and in combination with locating more plants overall, this will likely result in expedition the eradication process

ACKNOWLEDGEMENTS

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Abstracts

Russian Olive Symposium

Reframing the Social Values Questions that Underlie Invasive Plant Conflicts: Issues to Consider for Russian Olive

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ABSTRACT

Invasive species control is simultaneously an economic, ecological, and ethical act. Social values shape human perceptions of invasive species and control efforts against them. Social values can influence the success of proposed control projects, especially biocontrol projects. Twenty years after finding an appropriate biocontrol agent for *Psidium cattleianumn* (Strawberry guava), arguably the worst pest in Hawaii's rainforests, and 8 years after applying for federal release permits, no release has occurred. In contrast, a permit for releasing an exotic pathogen targeting *Nassella neesiana* (Chilean needle grass) in New Zealand was granted after a review period 68 days. These cases point to the importance of social values in the control of invasive plants. Invasive species control, including biocontrol, is a public interest science, which suggests the importance of collaboration with the public, or at least garnering some public input. Invasive species control projects, undertaken in the public interest, should be subject to some form of participatory public engagement. Many invasive species control projects are undertaken from a stance of prudence, the ability to anticipate what positive results could come from actions taken today. Fostering public engagement and social learning about invasive plants and the social values associated with them increases the likelihood of success of any control project, whether or not the project includes discussions of a novel biocontrol agent.

How One State Responded to the Problems Russian Olive Cause: Commercial Sales are Now Prohibited in Montana

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ABSTRACT

Once touted as a fantastic wildlife plant, Russian olive has more recently been described as an invasive alien, troublemaker, and *not* a friend of native plants (especially cottonwoods). One way to consider addressing the problems created by Russian olive is through adoption of state and local policies that restrict its use and distribution. Some local and state governments have chosen to list this plant as a noxious weed. For other states or locales, getting that listing is a difficult battle. In Montana, the state chose to prohibit its commercial sale by designating it as a 'regulated plant'. This prohibition was arrived at following a 2008 petition to the Montana Dept. of Agriculture submitted by Montana Audubon and the Montana Native Plant Society. The 'regulated plants' category, which was specifically created to manage Russian olive and several other plant species, recognizes that certain plants have the potential to have significant negative impacts; it then prohibits the plants from being intentionally spread or sold.

In this talk I will share our tactics—how we and our partners affectively built support, dealt with our adversaries, and changed state policy. The decision to categorize Russian olive as a regulated plant occurred in September 2010, after a lot of persistence and hard work—and several challenges to the status change. This victory should reduce the spread of this exotic, invasive plant.

The Biology of Invasive Plants: Russian Olive as a Case Study

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ABSTRACT

Invasive plant species generally are excellent at reproduction and tolerating environmental stress. Several studies have found a number of traits that are associated with invaders and Russian olive shares many of them. Reproductive traits include a short juvenile period, long fruit displays, and high seed viability. The seeds are bird-dispersed, which is common among invasive woody plants. Plants tolerate stress by fixing nitrogen, being able to lose leaves during cold or other stress, and resisting predation. Their wide edaphic tolerance also hints at their ability to withstand environmental stress. They are also known to invade outside the United States, another predictor of invasive success. The species was introduced in colonial times, giving it ample time to move through any lag phase, and it was commonly planted as a shelterbelt and ornamental species, increasing propagule pressure. In fact, the only trait it does not have in common with most woody invaders is that cold stratification increases germination – but without it, 50-60% of the seeds germinate (as opposed to 92% in one study with stratification). Given all these traits, it would be amazing if Russian Olive did NOT invade!

Water Use and Ecophysiology of Russian Olive and Cottonwood Trees

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ABSTRACT

Russian olive (*Eleagnus angustifolia* L.) was originally introduced to North America in the early 1900's. It has since become naturalized in 17 western U.S. States Relative to other riparian tree species, there is little data on the water relations, water use or impacts of Russian olive (RO) on the ecohydrology of riparian ecosystems, in part due to technological challenges associated with measuring water use in RO. Unlike most riparian woody plants that have diffuse porous wood anatomy, RO has ring-porous wood. The significance of ring porous wood is that sap flow occurs through xylem conduits that are much larger in diameter than in diffuse-porous wood and concentrated in the outermost growth ring. Unfortunately, most sap flow measurement techniques are engineered to measure uniform flow across a much larger cross-section of the stem than a single growth ring, making water use by ring-porous species such as RO difficult to quantify. Recent lab calibration studies, however, have greatly improved the accuracy of a widely used technique (thermal dissipation method) for measuring sap flow on ring-porous stems.

Under warm and dry atmospheric conditions (such as those that are typical in the arid west), ring-porous tree species such as RO often express a higher stomatal sensitivity to *vpd* than co-occurring diffuse porous tree species such as cottonwood and willow. These differences lead to the prediction that stomatal conductance and subsequent leaf-level water loss are typically lower in RO than diffuse-porous riparian tree species. However, recent measurements of stem sap flow using lab-calibration coefficients do not support these predictions. Sap-flux-scaled transpiration per unit basal area, measured near Salt Lake City, UT was on average about two-fold higher in Russian olive trees than in co-occurring Fremont cottonwood trees. Whether these sap flow patterns reflect annual differences in stand water use between RO and other species depends on several factors, including leaf phenology, stand density and leaf area index. The expansion of RO could have significant impacts on ecohydrological processes, particularly in watersheds that can support large floodplains relative to stream and groundwater discharge.

Geographic and Genetic Influences of Russian Olive Phenology

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ABSTRACT

The distribution of Russian olive (*Elaeagnus angustifolia* L.) in North America is characterized by a sharp southern boundary, running through southern California, Arizona, New Mexico and southwest Texas. Russian olive distribution is associated with cold winter temperatures, and its southern geographic limit appears to be associated with climate conditions (i.e., warmer winter temperatures) that are insufficient to meet the chilling requirements of Russian olive seeds and buds. Reduced seed germination and percentage bud break may limit Russian olive fitness near its southern range boundary in North America. If this is correct, warming temperatures could lead to northward shift of the introduced range. If insufficient chilling is limiting fitness near the southern range boundary, there could be local natural selection for a reduced chilling requirement.

The goal of this project was to examine the chilling requirement for bud burst of Russian olive populations across a latitudinal gradient in the western US. We collected fruits from six naturally occurring Russian olive populations in Colorado, New Mexico, and Texas in the spring of 2011 and 2012. Five hundred fruits were collected from each population in each year, from a minimum of 10 trees per population. Fruits were cold stratified for 60 days, and then germinated in propagation trays in a greenhouse. Seedlings were transplanted into pots and grown outdoors under ambient climate conditions in Boone, North Carolina until March, 2013. The two cohorts of Russian olive plants (cohort 1, collected/germinated in 2011; cohort 2, collected/germinated in 2012) were then transported to Fort Collins, Colorado. Plants were grown outdoors in a shade house at Colorado State University during the summer and fall of 2013. At weekly intervals between September, 2013 and January, 2014, groups of five plants from each cohort and population were brought indoors to the greenhouse and subjected to forcing conditions to test for bud dormancy. Percent bud burst was documented weekly for 10 lateral buds on two branches per plant. For each cohort/population, chilling requirement for bud burst was determined as the amount of cold chilling needed to achieve 50% bud burst within five weeks of forcing. The plants demonstrated a clearly defined chilling requirement. We also tested for variation in chilling requirement among collection sites.

Natural History and Population Biology of Russian Olive along Eastern Montana Rivers

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ABSTRACT

Russian olive (*Elaeagnus angustifolia* L.) is an exotic tree thought to be able to replace native riparian cottonwood forests in the western U.S. However, the underlying biology of this invasion has not been well studied. We recorded vegetative canopy cover of all species and measured basal area and used dendrochronology to estimate growth rate and age structure of Russian olive, plains cottonwood and green ash at 34 sites on Marias and Yellowstone Rivers in eastern Montana. We also quantified damage to all trees due to beaver activity.

Unlike most invasive plants, Russian olive is a late-successional species; disturbance is not necessary for Russian olive to invade. Russian olive occurs in multiple-age stands on terraces with a dense ground layer and mature cottonwood but rarely establishes in recently flood-deposited alluvium. Russian olive attains reproductive maturity at ca. ten years of age in Montana, and, on average, there was less than one new plant recruited per mature tree per year. Russian olive grew at nearly three times the rate of the native late-successional green ash at sites where both occurred. Russian olive invasion proceeds slowly compared to many exotics due to its long maturation time and low recruitment rate.

Beavers can play an important role in Russian olive attaining dominance invasion by removing the cottonwood trees while having little impact on the invader. Beaver foraging damaged the majority of cottonwood trees within 50 m of most river channels sampled, but only 21% of stands farther away were affected. Russian olive suffered little damage regardless of location. Cottonwood establishment and dominance will not be precluded on unregulated rivers where flooding events reinitiate primary succession beyond the zone of beaver activity. However, cottonwood establishment is often restricted to lower terrace sites along regulated rivers, and here beaver prevent cottonwood from developing a mature canopy close to the river while having little effect on the continued invasion of Russian olive.

Current Russian Olive Distribution along Montana Rivers

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ABSTRACT

Precise and accurate mapping of Russian olive is a necessary precursor to estimating habitat loss, recognizing spatial patterns in distribution and abundance, and identifying areas where targeted management efforts might be most effective. For some uses, mapping can be coarse scale, especially if currency and repeatability are the most important attributes. For other purposes, fine-scale mapping is required. We have experimented with two broad approaches to mapping Russian olive extent and distribution in the Yellowstone River Basin in Montana. One uses commonly available and easily manipulated Landsat 30m imagery, while the other exploits 1m National Agricultural Imagery Program (NAIP) aerial photography. In this presentation, we will discuss the pros and cons of each approach, and discuss the results we have obtained with each. The presentation is geared towards an audience of professionals who use mapping derived from image classification rather than image analysts, although people will remote sensing and GIS backgrounds should also find it informative.

Preliminary Insights into the Geography and Ecology of Russian Olive in Canada

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ABSTRACT

Invasive species managers are paying increasing attention to Russian olive as a potential threat to riparian ecosystems within Canada. The scope of the threat is difficult to asses, due in large part to the lack of information about the plant's past, present, and future potential distribution across the country, and about its impacts on the native flora and fauna. We will present our lab's findings concerning (i) historical shelterbelt plantings, (ii) niche model predictions of potential future distributions, and (iii) insect assemblages associated with Russian olive trees in the south Okanagan region of BC. We will first present maps depicting the staggering geographic scope of the Government of Canada's (now discontinued) Prairie Shelterbelt Program, which included the planting of more than 1 million Russian olive seedlings. We will then describe how we added 1484 occurrence records of RO in southern BC (an increase of 5017%) by conducting "remote surveys" on Google Earth and Google Street View. Next, we will show predictions of Russian olive's potential distribution across North America (focusing on Canada), derived from continent-wide occurrence records and Maxent niche models. Lastly, we will present preliminary findings concerning the composition of insect assemblages associated with Russian olive plants and two commonly co-occurring plants, Saskatoon (*Amelanchier alnifolia* Nutt.) and Woods' rose (*Rosa woodsii* Lindl.).

Ecosystem Impacts of Russian Olive are Strongly Mediated by Ecological Context

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ABSTRACT

In 2008, the Three Rivers Alliance initiated a project to remove Russian olive along the Arikaree and Republican rivers in eastern Colorado. As part of this effort, we are investigating the effects of Russian olive and removal efforts on soil N, available light and plant community structure. Three years of data from over 400 paired, permanently marked plots demonstrate that plots associated with Russian olive have a more than 2-fold increase in available soil N and less than 1/2 the available light of reference plots. This change in resource availability under Russian olive results in a plant community with lower cover from native perennial grasses and greater annual grass and exotic forb cover than is seen in comparable reference plots.

We also used Non-metric multidimensional scaling (NMDS) with ordination and a series of mixed-model ANOVAs to examine if any of several environmental variables contribute to the strength of the Russian olive effects. ANOVA and NMDS analyses determined that both position within the riparian system (within the channel bed vs. historic flood plain vs. perennial wetland) and the presence of gallery cottonwood forests influence the magnitude of Russian olive's effect on available N, light and plant community composition. Russian olive's effect on soil N and light was greater in open areas than under cottonwood forest, and this translated into a greater effect on plant community structure in these habitats. Similarly, Russian olive had a greater impact on soil N (but not light) in plots located within the channel bed than the historic flood plain, and this translated into greater impacts on plant community structure as well.

Our results indicate that the impact of Russian olive on ecosystem processes is context dependent, and that there are greater effects of the exotic tree on both biotic and abiotic responses in areas with higher resource water and light availability.

Bat Activity in Riverine Stands of Native Plains Cottonwood and Naturalized Russian Olive in Southeastern Montana

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ABSTRACT

Replacement of native riverine gallery forests by woody exotics is a significant conservation issue throughout the western United States. Controversy surrounds the management of Russian olive (*Elaeagnus angustifolia* L.), a small Eurasian tree now naturalized in the west, because its detrimental effects to native vegetation are offset to some degree by resources (food and cover) it provides for some wildlife species. Through use of electronic bat detectors we measured the relative activity of bats in stands dominated by plains cottonwood (*Populus deltoides* Bartr. ex Marsh.) or Russian olive along the Yellowstone and Powder rivers in southeastern Montana. Ten bat species total were recorded during late July to mid-September 2011 in 18 stands (12 cottonwood, 6 Russian olive). Bats were detected in all stands, but activity was greatest in those dominated by cottonwood. Bat activity was also positively correlated with percent canopy cover of cottonwood, negatively with percent canopy cover of Russian olive. Snags and dead limbs, loose bark, and cavities, all important roosting habitat for bats, were most prevalent in cottonwood stands; cavity-making birds (woodpeckers, nuthatches, chickadees) were also significantly more evident in cottonwoods. We conclude that Russian olive in the northern Great Plains is inferior riverine habitat for bats relative to native cottonwood gallery forest.

Effects of Russian Olive on Stream Organisms and Ecosystem Processes

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ABSTRACT

Russian olive (Elaeagnus angustifolia) is a non-native riparian tree that has become common and continues to spread throughout the western United States. Due to its dinitrogen-fixing ability and riparian habit, Russian olive has the potential to subsidize streams with nitrogen, which may alter nutrient dynamics in these systems. Furthermore, it has the potential to alter stream organic matter budgets by adding leaf litter and olives to and changing primary production due to shading. Inputs from Russian olive may alter the composition of food resources for stream animals, native and nonnative, which could influence their abundance and productivity. Here we summarize a combination of recent and ongoing studies aimed at investigating the suite of direct and indirect ecological effects Russian olive may elicit in streams. A comparative study of stream reaches in Idaho and Wyoming invaded by Russian olive had higher organic nitrogen concentrations and exhibited reduced nitrogen limitation of aquatic primary producers compared to reference reaches, though background nitrogen levels of streams appeared to mediate their potential to retain versus export additional nitrogen from Russian olive. Using a before-after invasion comparison at Deep Creek, Idaho, we found that Russian olive invasion was associated with a significant increase in litter input to the stream and that this litter was recalcitrant compared to that of native willow. In this stream, Russian olive invasion was associated with a 4-fold increase in organic matter stored in the streambed, but not significant changes in gross primary production or community respiration, translating into a 30% decrease in ecosystem efficiency. We found no significant change in total secondary production of invertebrates in response to the altered food base, though there were changes in some individual taxa. Diet and stable isotope evidence indicate that Russian olive litter is selected against by the dominant, native macroinvertebrates because it is used in lower proportion relative to its availability. On the other hand, ongoing studies in Deep Creek reveal that invasive carp (Cyprinus carpio) consume large quantities of olives and that their numbers have dramatically increased since the trees established, whereas abundance of the remaining native fishes (which generally cannot make use of Russian olive material) have declined over the same period. Russian olive invasion appears to alter multiple stream ecosystem functions and may contribute to shifts in stream food webs via interactions with other invasive species.

Efficacy of Herbicide Ballistics Technology for the Control of Salt Cedar and Russian Olive in Fremont County, WY

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ABSTRACT

A study was established to evaluate the usefulness of Herbicide Ballistics Technology for the control of Salt cedar and Russian olive by selecting one hundred plants of each species along Five Mile Creek, a tributary to Boysen Reservoir 20 miles north of Riverton, Wyoming. Each plant was photographed, evaluated for height, width, and number of stems, and identified with numbered tags. Treatments and checks were assigned randomly. Standard foliar, cut stump and basal bark treatments were compared to Herbicide Ballistics Technology, HBT, a pesticide application technique developed by Dr. James K. Leary, University of Hawaii, where a standard 2 milliliter paint ball was loaded with oil and herbicide mixtures of Triclopyr and Imazapyr and fired with compressed air at the target plants from a distance. The herbicide is released on impact. Doses of 6, 12, 18 and 24 herbicide loaded balls were applied to one side of the plants 12 to 15 inches from the ground. Plants were evaluated at 12 and 24 months after treatment. A dose response curve for Triclopyr and oil was established for Salt cedar that could be used to fine tune the application methods and rates to get results comparable with currently labeled basal bark and cut stump applications while using a significantly reduced amount of active ingredient. Imazapyr treatments were less consistent on both species and resulted in non-target injury to nearby plants. Potential certainly exists to use HBT with the Triclopyr and oil mixture for Salt cedar control on scattered populations in rough country. On Russian olive the results were inconsistent with both herbicides at the tested application rates. Russian olive control was generally poor suggesting that HBT would have limited application for the control of that species.

Russian Olive Management Along the Marias River in Montana

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ABSTRACT

In 2008, the Marias Watershed group initiated an innovative demonstration project to evaluate costs, logistics, and operational issues necessary to conduct a full-scale Russian olive removal project on the Marias River. The project's goal was to evaluate various technologies and approaches to remove Russian olive in a riparian area. The project demonstrated and evaluated Russian olive removal treatments for success and cost effectiveness to be used as a model for the rest of the Marias River and other rivers/streams throughout Montana. Control methods demonstrated in the project were: basal bark herbicide treatment, cut-stump herbicide treatments following cutting with a gyro-track mulcher, cut-stump herbicide treatments with "hot-saw" cut trees, cut-stump herbicide treatments with chain saw cut trees, foliar application of herbicide to seedlings, and foliar applications of herbicide to mature trees. Cut-stump and basal bark treatments were made using a herbicide mix of 1/3 Remedy Ultra (triclopyr) and 2/3 basal bark oil.

Results of the demonstration project showed poor control of trees cut or mulched to ground level. The mulcher did extensive damage to the stumps and removed the bark completely in most cases. This, in turn, destroyed the cambium layer under the bark which is used to translocate nutrients throughout the tree and root system. With no bark remaining to absorb the herbicide, root uptake of herbicide was poor, and thick, bushy regrowth emerged from these stumps the following year.

Trees cut cleanly to a height of 18"-24" that were treated, absorbed the chemical completely. A 90-95% success rate was achieved in the first year on all trees that had been cut cleanly, leaving the bark intact. This included the hot-saw, chain saws, or pruners. We had very poor control with basal bark treatments on mature trees with trunks over 3" in diameter that had not been cut. A great deal of success was found on young trees and seedlings with foliar treatments.

Tracking Ecosystem Recovery after Russian Olive Removal – Lessons Learned and Moving Forward

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ABSTRACT

Russian olive was removed from large plots along the Yellowstone River in 2011. Pre-removal vegetation, soils, and insect data were recorded to compare trajectories in these communities to trajectories in nearby reference plots where Russian olive was not removed. Removal using a tree shear with immediate application of 1:3 triclopyr to basal bark oil was extremely successful with less than half a percent of stumps resprouting the following year. A severe flood in spring of 2011 caused root resprouting of about 4% of the cut trees. Russian olive seedling densities in removal plots in fall of 2011 were twice those of reference plots, possibly due to the flood. Tamarisk seedling densities were also high in removal plots – all weedy trees in removal areas were foliar sprayed in 2012 and 2013 with 1oz triclopyr: 3 tsp aminopyralid mixed with less than one ounce of surfactant. Herbaceous species were seeded and trees and shrubs were transplanted into restoration plots within removal plots in spring of 2012. Controls where Russian olive was removed but revegetation was not conducted were also established. By 2013, there were no significant differences in understory cover between controls and revegetated plots, because establishment of seeded herbaceous species was very low. Soil analyses showed that nematodes, fungi, and ciliates did not respond to Russian olive removal. Soil bacteria communities were dynamic and showed opposite trajectories in removal and reference plots. Further investigations on how Russian olive removal impacts soil function will focus on bacterial communities. Further research will explore the use of additional reference plots due to the fact that our original reference plots now have different flooding history than our removal plots. Also, insect community and game camera data may show us if animal utilization of removal areas differs from Russian olive-dominated areas.

Monitoring the Efficacy of Treatments on Saltcedar (*Tamarix spp.)* and Russian Olive (*Elaeagnus angustifolia L.)* Bioenergy Investigation – Utilization of Saltcedar and Russian Olive as Feedstocks for Bioenergy Applications

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ABSTRACT

Russian olive (*Elaeagnus angustifolia* L.) and saltcedar (*Tamarix spp.)* are native Eurasian species introduced to North America as ornamentals in the 19th century. Subsequent escape from cultivation led to establishment over millions of riparian habitat. Both species disrupt riparian ecosystem function through competition and displacement of native plant species, degradation of native wildlife habitat, reduction of recreational access, and agricultural utilization. Efforts to eliminate these target species have been somewhat unsuccessful, as initial treatments are often followed by secondary invasions of undesirable plant species.

Numerous methodologies employed for species removal have provided limited information on desirable long-term results following initial treatment and removal. Synergy Resource Solutions Inc. monitored treatment and control sites to determine pre-treatment conditions and post-treatment conditions of treated saltcedar and Russian olive invasions. Continued employment of methods utilized for baseline monitoring will demonstrate the long-term efficacy of treatment methods and the influence of initial site conditions on results.

Woody biomass primarily generated from forest harvesting activities, such as various pine species have been used successfully as the fuel source for heat and power generation for the last two decades in the western United States. Testing and independent analysis of saltcedar (*Tamarix spp.)* and Russian olive (*Elaeagnus angustifolia L.)* was employed to identify the potential utilization of the target species as feedstock for woody biomass energy applications as an innovative alternative for biomass reduction in riparian invasive plant management.

Community Response to Russian Olive Control/Removal Projects

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ABSTRACT

Hot Springs County Weed and Pest Control District has been engaged in a battle against Russian olive and Tamarisk invasion since 2003. These efforts have been part of a larger project throughout the Bighorn Basin to clear these invasives from tributary drainages to the Bighorn River with the end goal of removing them from the river corridor itself. By 2011 these outlying populations had been mostly cleared and reintroduction of natives was well underway, so in 2012, with funding from a number of partners in place, large removal projects were begun on the Bighorn River. Response from residents of the District had been almost entirely positive, and those who opposed the removal of Russian olives and tamarisk simply opted not to be involved in control programs. When large scale work began on the very visible Bighorn River, opposition became more pronounced and aggressive. Most dissatisfaction with removal was based on the perception that wildlife habitat was being depleted. Rehabilitation of infested areas has been a very important part of the control of these invasives all along, albeit with varying speed of recovery in disparate areas. In cases where we were given a chance to explain the whole program to those who disliked the removal, usually the displeased party was much more willing to give weed control agencies a chance to help with habitat recovery. There are still holdouts of course, and it will be years before there is enough data to show how the rehabilitation of Russian olive and tamarisk infested area is affecting wildlife in the Bighorn Basin.

Russian Olive and Salt Cedar Management Challenges Along the Shoshone River and Clark's Fork River in Wyoming

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ABSTRACT

In 2010, the Shoshone River and Clark's Fork River CRM was created to focus on the control of Russian olive and salt cedar. The project's goal was to eradicate as much Russian olive and salt cedar as possible and to return the riparian ecosystems to a fully functioning native system. The Shoshone River portion began at the Buffalo Bill reservoir and continued to the Park/Big Horn county line, and included all major tributaries. The Clark's Fork portion began at the Clark's Fork canyon and extended to the Wyoming/Montana state line, and included all major tributaries. The project faced many challenges as people's opinion of removing Russian olive and salt cedar varied wildly. Many landowners were enthusiastic about control and began projects as soon as funding was available. Other landowners were reticent and refused to enter into any control project. The major challenge to this project was the values that people assigned to Russian olive and salt cedar with some viewing them as noxious weeds, while others viewed them as critical wildlife habitat. Funding sources included Park County Weed & Pest Control District, Wyoming Wildlife & Natural Resource Trust, NRCS, Wyoming Game & Fish, and private landowners.

River of Time, Wyoming's Evolving North Platte River

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ABSTRACT

The North Platte Drainage System flows through five counties in southeast Wyoming. The impact of noxious weeds such as Russian olive and Salt Cedar has become a major problem. The five counties, Goshen, Platte, Converse, Natrona and Carbon, organized into the "Upper North Platte River Weed Management Area" to combine efforts to address this problem.

The DVD "River of Time, Wyoming's Evolving North Platte River" depicts the programs in each county, the pros and cons of the efforts and the techniques used to address these problems. Partners included Conservation Districts, private landowners, BLM, WY Game and Fish, NRCS, Goshen County Weed and Pest, WY Department of Agriculture and others. The video was produced and directed by Becky McMillen, Insight Creative Independent Productions of Scottsbluff, NE.

Lessons Learned from Biocontrol of *Tamarix* spp. Applied to Russian Olive

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ABSTRACT

Tamarisk (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*) are both woody invasive species covering vast areas of the western US. Both are viewed as undesirable with negative ecological and economic impacts and because of this have been targeted in numerous large scale control programs. Although there are candidate biocontrol agents for Russian olive, none has been approved for open field release. In contrast, there is a large scale tamarisk biocontrol program now underway which has been both successful and controversial. Given the similarities between tamarisk and Russian olive it is valuable to consider the history of the tamarisk biocontrol program when planning for Russian olive biocontrol. In this presentation we will review the history of the tamarisk biocontrol program including the pre-release development phase (1970s to 2001), the initial open field release and evaluation phase (2001-2005) and the large scale implementation phase (2005-present). The review will include a discussion of the points of controversy in tamarisk biocontrol development, including the value of tamarisk as wildlife habitat, particularly for the endangered southwestern willow flycatcher, the potential for biological control to result in water savings as well as the long term outlook for riparian restoration in the presence of tamarisk biocontrol. We will discuss the value of basic and applied research, site monitoring, stakeholder consortia, public education and the engagement of policy makers in the tamarisk biocontrol program with a view toward the future and potential success of Russian olive biological control.

Development of a Classical Biocontrol Project for Russian Olive and Issues to Consider for Targeting a Conflict Species

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ABSTRACT

Because of the potential benefits of planting Russian olive near human settlements, developing a classical biological control programme against it could give rise to a conflict of interests. Initial efforts to assess the prospects of classical biological control of Russian olive therefore focused on identifying and studying biological control candidates that reduce the seed output and hence the spread of this invader, without killing established trees. During surveys in the native range of Russian olive in Asia, several invertebrate species have been found attacking the reproductive parts of this tree. Up to date, two invertebrate species have been selected for in-depth studies: the mite *Aceria angustifoliae*, which attacks leaves, inflorescences and young fruits of Russian olive, and the moth *Ananarsia eleagnella*, which mines the shoot tips and the fruits of Russian olive trees. I will provide an overview of the current state of the pre-release studies on the host-specificity and impact of these two biological control candidates.

Plenary Session

How Did We Get Here: A Very Brief Introduction to Invasive Ornamental Plants

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ABSTRACT

Many, if not most, plants used in horticulture today are not native to the places they are used. Introductions have long been celebrated for their beauty and utility. However, many traits that make a plant desirable as an ornamental, such as ease of reproduction and the ability to flourish under many conditions, are also traits facilitating invasion. In just a few decades time people who introduce plants have gone from being viewed favorably to feeling like they are under attack. Understandably, they have not always responded well; in many ways their reactions are some akin to grief. Codes of conduct, a sort of best management practice approach, are helpful for horticulturists to understand a path to responsible plant introductions in light of current knowledge. The conversations continue to evolve, including an increased focus on potentially sterile cultivars, which have many caveats, and policy options. As with all contentious discussions, understanding of, and respect for, all points of view, improves the outcome.

Linking Theory, Empiricism and Practice in Invasive Plant Management

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ABSTRACT

Efforts to produce strong scientific support for the management of weedy and invasive plant species can benefit greatly from ongoing, iterative communication among practitioners, field ecologists and theoreticians. Providing both synergy as well as checks and balances, these complementary perspectives can help to focus research agendas in ways that lead to useful information for stakeholders. In this presentation, I use examples from quantitative risk analysis of invasion potential of bioenergy crops in the genus Miscanthus to demonstrate how practice, empiricism and theory may be linked to aid invasive plant management.

A Historical Overview of Biological Control of Weeds in Wyoming

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ABSTRACT

Biological control of weeds got off to a slow start in Wyoming. In comparison to herbicide based control activities potential yield responses in crops were very small if any and research looked like a black hole where funds simply disappeared. While many states around us embraced the great potential biological control had to offer, Wyoming was content to sit back and wait for the efforts of others to trickle down. Reports of promising agents for the control of Leafy spurge increased interest and several Wyoming Weed and Pest Districts contributed in minor ways to the research effort. An effective Biocontrol Steering Committee was established and a coordinated effort has been made to see that all available agents are released in Wyoming and were they establish to systematically redistribute them across the state. USDA/APHIS/CAPS at the University of Wyoming has served as a central data collection point that currently has 27,000 records on 55 agents which have been released on 18 target weed species since 1975. Post release monitoring has documented the establishment of 28 of the agents in the state and has measured significant impacts, at least locally, on six of the target weeds. A very large data set exists tracking the impact of *Aphthona nigriscutis* on Leafy spurge. Musk thistle has collapsed in Fremont County from 11,000 acres of monotypic stand in 1980 to 700 acres of scattered plants today. Dalmatian toadflax is similarly in decline. *Aceria malherbae* appears to have good impact on Field bindweed in cropping systems. Post release monitoring first identified non-target feed by *Aphthona* on a native plant, *Euphorbia robusta*, and then demonstrated that the feeding was incidental to high leafy spurge population and went away as the Leafy spurge declined. Hundreds of acres of Salt cedar are being defoliated. The success of these programs has resulted in a growth in Wyoming's commitment to biological control of weeds research with annual consortium contributions exceeding $250,000 for the last decade. Equally important has been the local commitment to biological control where half of the Weed and Pest Districts in the state have staff dedicated to biological control implementation and post release monitoring.

Lessons Learned from a Long-term, Collaborative Weed Eradication Program

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ABSTRACT

With declining or fluctuating budgets, new invaders, shifting land uses, and changing climate, effective weed management is as challenging as ever. The choices managers make today have long-term consequences for the native plant communities we value, and integrating weed management, monitoring, and research is critical to improving our decision-making processes. Since 1999, the Red Rock Watershed Weed Program has been dedicated to managing and eradicating invasive plants from a headwater basin of the Missouri River. This collaborative effort among private landowners, Beaverhead County, federal and state agencies, and the Conservancy has invested substantial time resources enhancing native plant communities in our landscape and has engaged in research to refine our approaches. We have employed intensive community outreach, mapping, chemical and mechanical management, ecological modeling, and monitoring to guide strategies and maximize the likelihood of long-term success. During this process, we have learned valuable lessons about what has or has not help achieve our biological objectives across a large, complex landscape with mixed land ownership. These lessons will be shared in this presentation to stimulate discussions about how we prioritize strategies across the Northern Rockies.

Ecology & Genetics of Plant Invasions

Does Forage Kochia Spread from Seeded Sites? An Evaluation from Southwestern Idaho

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ABSTRACT

Purposeful introductions of exotic species for rehabilitation efforts following wildfire are common on rangelands in the western US, though ecological impacts of exotic species in novel environments are often poorly understood. One such introduced species, forage kochia (*Kochia prostrata*) has been seeded on over 200,000 ha throughout the Intermountain West to provide fuel breaks and forage, and to compete with invasive plants. Despite its potential benefits, it has been reported to spread from some seeded areas, and no studies have addressed its potential interactions with native species. We sampled 28 forage kochia post-fire rehabilitation and greenstrip seedings in southwestern Idaho, which ranged from 3 to 24 yr since seeding. We analyzed cover of forage kochia and the associated plant community in adjacent seeded and unseeded areas, and quantified extent of spread from the seeding boundary. Forage kochia spread to unseeded areas on 89 % of sampled sites; distances of the farthest individual from the seeding boundary were greater than those previously reported, ranging from 0 to 710 m, with a mean distance of 208 m. Further, while spread increased with time since seeding, it was apparently independent of the composition of communities into which spread occurred. Results contribute to current understanding of potential ecological implications of seeding forage kochia and will enhance the ability of land managers and private landowners to make scientifically-based decisions regarding its use.

Using Environmental DNA for the Early Detection of Eurasian Watermilfoil (*Myriophyllum spicatum*)

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ABSTRACT

Early detection of aquatic invasive species is a critical task for management of aquatic ecosystems. This task is hindered by the difficulty and cost of thoroughly surveying aquatic systems. Eurasian water milfoil (EWM; *Myriophyllum spicatum*) is an aquatic invasive plant in the Northern Rockies that alters the native plant community and impedes recreation after it invades. If detected early, eradication of EWM is possible but detection is impeded by laborious and expense survey techniques and difficulty with EWM identification using morphological characteristics alone. For these reasons, novel surveillance tools relying on DNA-based identifications are needed. To improve early detection capabilities for EWM, we developed and validated a highly sensitive environmental DNA (eDNA) protocol; eDNA monitoring enables the identification of organisms from DNA present and collected in water samples. We collected 1 L water samples from 376 L tanks containing varying densities (0 – 50 plants) of EWM. We detected EWM concentrations in all tanks, regardless of plant density but eDNA was detected more consistently at higher plant densities. We used the same protocol to confirm the presence of EWM eDNA in rivers and lakes in Montana and Michigan with known populations of EWM. Combined, these results demonstrate the high potential for eDNA monitoring to assist with the early detection of aquatic invasive plants like EWM.

Invasion of Medusahead (*Taeniatherum caput-medusae*) in the Western United States: Geographic Origins, Multiple Introductions and Founder Effects

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ABSTRACT

The native range of *Taeniatherum caput-medusae* includes much of Eurasia, where three distinct subspecies have been recognized, but only *T. caput medusae* ssp. *asperum* (hereafter referred to as medusahead) is believed to occur in the United States (U.S.). Medusahead, a primarily self-pollinating annual grass, was introduced into western U.S. in the late 1800s. The results of an earlier allozyme analysis were consistent with the genetic signature associated with multiple introductions, although this finding can only be confirmed with the analysis of native populations. I compared allozyme diversity in native and invasive populations of medusahead to: identify the geographic origins of the U.S. invasion, test the multiple introduction hypothesis and determine the genetic consequences of these events. Thirty-four native populations of medusahead were analyzed in this study, using enzyme electrophoresis. Five of the seven homozygous multilocus genotypes previously observed in the western U.S. have been detected in native populations. These results provide support for the multiple introduction hypothesis. The geographic origins of these introductions appear to have been drawn from France, Sardinia, Greece and Turkey (Fig. 1); although additional analyses are needed. Across native populations, 17 of 23 loci were polymorphic and a total of 48 alleles were detected, while only five polymorphic loci and 28 alleles were found among invasive populations. On average, invasive populations possess reduced within-population genetic diversity, compared with those from the native range. While U.S. populations have experienced founder effects, 38% (17 of 45) these populations appear to be genetic admixtures (consisting of two or more native genotypes). Results of this study have implications for the biological control of medusahead: i) the search for effective and specific biological control agents will have to occur broadly across the species' native range, ii) multiple agents may be required to control invasive populations that are admixtures, and iii) because many invasive populations are genetically depauperate, highly adapted biocontrol agents are likely to be quite effective.

Extreme Differences in Population Structure and Genetic Diversity for Three Invasive Congeners: Knotweeds in Western North America

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ABSTRACT

Japanese, giant, and the hybrid Bohemian knotweeds (*Fallopia japonica*, *F. sachalinensis* and *F. x bohemica*) have invaded the western USA and Canada, as well as other regions of the world. The distribution of these taxa in western North America, and their mode of invasion, is relatively unresolved. Using Amplified Fragment Length Polymorphisms of 867 plants from 132 populations from British Columbia to California to South Dakota, we determined that Bohemian knotweed was the most common taxon (72% of all plants). This result is in contrast to earlier reports of *F. x bohemica* being uncommon or non-existent in the USA, and also differs from the European invasion where it is rare. Japanese knotweed was monotypic, while giant knotweed and Bohemian knotweed were genetically diverse. Genotypic data suggests that Japanese knotweed in western North America spreads exclusively by vegetative reproduction, whereas Bohemian knotweed spreads by both seed and vegetatively, over both long and short distances. Giant knotweed populations were mostly monotypic, with most containing distinct genotypes, suggesting local spread by vegetative reproduction. Spread of giant knotweed over long-distances appears to be by seed or alternatively there have been multiple introductions of different genotypes to separate locations. The high relative abundance and genetic diversity of Bohemian knotweed make it a priority for control in North America.

Outreach, Social Media & New Technologies

EDDMapS & EDDMapS Smartphone Apps

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ABSTRACT

EDDMapS' primary goal is to discover the existing range and leading edge of invasive species while documenting vital information about the species and habitat using standardized data collection protocols. EDDMapS allows for data from many organizations and groups to be combined into one database to show a better map of the range of an invasive species. Goals of the current project include: integration of existing regional datasets, increase search options on EDDMapS website, update NAWMA Invasive Plant Mapping Standards, and coordinate with local, state and regional organizations to develop early detection networks. After eight years of development of EDDMapS, it has become clear that these local organizations are key to developing a successful early detection and rapid response network. The University of Georgia Center for Invasive Species and Ecosystem Health has released 15 apps to support data entry into EDDMapS.

A Hybrid Approach to Real-time Data Collection and Mapping of Noxious Weeds

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ABSTRACT

iFormbuilder was created by a company called Zerion and is an out of the box mobile data collection solution that the Washington State Department of Agriculture has been using for the past year. It features both an iOS and Android mobile application as well as a web based form creation and data management interface. iForm has proven to be highly flexible, easy to use and highly customizable using basic Javascript code. This past Summer WSDA utilized iForm for over 15 different statewide invasive weed and insect surveys and collected over 140,000 individual electronic records. iForm is a near real-time data collection system that also offers the ability to collect data when out of cellular coverage. Zerion has recently formed a partnership with ESRI and their product now works very cohesively with ArcGIS Online(AGOL) and ArcMap. ESRI provided WSDA with a custom ArcMap extension that allows for the direct download of iForm data which is then automatically inserted into a geodatabase as a feature class. It also offers the ability for a completely automated way of creating a REST feature service on your AGOL account directly from a form you have created within iForm. This will allow WSDA to have near real-time access to the REST feature service within our AGOL web maps and applications as well as various ESRI web based FLEX mapping applications developed internally. Transitioning to this new system has allowed WSDA to be up and running within a month of purchasing the product license and cut costs and data management time by over 40% from the previous year. The software was mainly utilized by WSDA staff but due to the success of the 2013 field season we will be rolling this out to county, state and federal cooperators in 2014.

The New Online Version of "Biological Control of Weeds – A World Catalogue of Agents and Their Target Weeds"

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ABSTRACT

During the past four-years, a team of colleagues has assisted Rachel Winston in a monumental effort that has resulted in the completely revised 5th edition of Julien & Griffiths (1998), "A World Catalogue of Agents and Their Target Weeds". The comprehensive revision and expansion of the catalogue now includes information on 224 target weeds and 551 biological control agent organisms. The information is based on 2043 total entries and the catalogue uses 2081 cited references. Because of the sheer amount of information we planned from the beginning of the project to also make the catalogue available as an online version. In this presentation, we will introduce the new online version, detail some of its additional information that could not be included in the print version, demonstrate some of the query functionality and finally outline some goals regarding the maintenance, expansion and usability of the database.

iBiocontrol – Tools to Support Biological Control of Weeds

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ABSTRACT

iBiocontrol is an iOS application, Android application and website that brings the power of EDDMapS Biocontrol to the on-the-ground land managers. Data collection is completed electronically and in real time from the handheld device. When wireless connectivity is unavailable, information is stored on the device until cellular or WiFi connectivity is available. iBiocontrol includes a complete field guide of agents and their host plants using existing USFS publications and images in the Bugwood Image Database System. This allows for a full library of information to be stored on a device that will easily fit in your pocket (iPhone/iPod Touch/Android) or backpack (iPad). Users will have a device that can be used to both manage biological control agents of invasive weeds and provide the full functionality of a phone or tablet device.

The iBiocontrol web portal provides access to the World Catalogue of Biological Control Agents and Their Target Weeds, the Proceedings of International Symposia on Biological Control of Weeds, Biocontrol in Your Barkyard – a Youth Biocontrol Education Program and various publication focused on the biological control of weeds. iBiocontrol is a collaborative effort of The University of Georgia, University of Idaho, CABI Bioscience and the U.S. Forest Service.

Native Plant Communities & Re-vegetation

Long-term Restoration of Severely Degraded Grasslands: Development of Seeding Regimes Which Increase the Success of Restoring Areas Severely Degraded by *Euphorbia esula* (leafy spurge) and *Bromus tectorum* (cheatgrass)

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ABSTRACT

Restoration of native plant communities on sites severely degraded by invasive plants is difficult. In grasslands where non-native plant communities have persisted for decades native plants and native soil seed banks are often so depleted that land managers must reintroduce native plants. Applications of native seed following weed control are commonly recommended but seeding can be costly and the success of establishing native plants from seed is variable. In this study, we compared four different seeding regimes to determine which was most successful at establishing native species on a site where multiple years of sheep-grazing had been used to control Euphorbia esula (leafy spurge). All seed was applied at the same rate but the applications of the seed varied across time (spring 2009- fall 2011) as follows: 1-time fall seeding (1F), 1-time spring & fall seeding (1S&F), repeated seeding for 3 falls (3RF), repeated seeding for 3 springs & falls (3S&F). All seeding regimes were replicated in an area where sheep grazing continued and in an area where sheep grazing was halted. We measured percent cover of all plant species and the density of all seeded native forbs on site. This study is on-going but preliminary results depict higher rates of seedling establishment when seeding regimes are split between multiple seasons (1S&F, 3RF and 3S&F) versus a one-time seed application in the fall (1F). In general initial seedling establishment was greater and mortality was lower on plots where sheep grazing was allowed to continue versus where grazing was halted. General management recommendations for controlling invasive plants by sheep grazing, incorporating a seeding regime into a grazing program and maximizing establishment of native plants by seed will be discussed.

Competition and Facilitation Among Plants in Restoration of Disturbed Lands

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ABSTRACT

Plant-plant interactions can be important in determining rates of establishment and persistence in restoration seedings. One of the primary motivations for performing restoration seeding is to utilize the phenomenon of competition as a tool, increasing the density of native plants in order to reduce the densities of undesirable plant species. Particularly at the seedling stage, and especially in arid and semi-arid systems, facilitation where plants increase survivorship of their neighbors is important and may be applied to problems in restoration. Revegetation contractors in eastern Montana- western North Dakota oil fields commonly sow annual grasses simultaneously with desirable perennial grasses in order to show immediate green-up on disturbed lands and to provide some forage for cattle. Does competition or facilitation dominate the outcome of this simultaneous seeding procedure? I found that while there is the potential for annual grasses to compete with perennial grasses in well-watered farm soils, the stressful soil of the disturbed land rendered competition unimportant, and facilitation may have been at play in shielding establishing perennial grasses from grazing in the first year. Annual grasses did not persist in the revegetation area, possibly due to grazing pressure from cattle, although the effect of cattle on annual grass persistence needs to be determined by additional experiments.

Developing an Integrated Pest Management Strategy for Controlling Ventenata (*Ventenata dubia*) in Timothy Hay and Conservation Reserve Program in the Pacific Northwest

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ABSTRACT

Ventenata (*Ventenata dubia*) is a non-native winter annual grass that has invaded perennial grass-dominated agricultural systems throughout the Pacific Northwest. The objective of this study was to evaluate techniques for ventenata control across two infestation levels of ventenata, expressed as foliar cover (high, >50% and low, <25%) within timothy hay and Conservation Reserve Program (CRP) using an integrated pest management (IPM) framework. Foliar cover and plant biomass for ventenata and desirable perennial vegetation were measured along permanent transects, using a line-point intercept method and 25 cm by 50 cm sampling frames. We evaluated fertilize only, fall herbicide only (flufenacet plus metribuzin), fertilize plus herbicide and a control treatment at a 5 cm and 10 cm cut height in timothy hay. In CRP, we evaluated the following treatments alone and paired with a fall herbicide (sulfosulfuron): fall burn, spring burn, sickle mow and remove, rotary mow, fertilize, and a control. In timothy, we found that treatments performed much better in high infestations than low when comparing ventenata biomass. Yield and ventenata control did not differ between the two cut heights. CRP treatments responded differently in ventenata control at the two infestation levels however, fall burn plus herbicide performed the best in both situations. Regardless of system or infestation level, an herbicide application significantly decreased ventenata percent cover and biomass but we saw increased control when integrating treatments. Results from our experiments will be used to create a decision support tool that utilizes annual grass cover and type of perennial grass system to assist land managers in making decisions within an integrated pest management framework.

Integrating Herbicides and Re-seeding to Restore Rangeland Infested by an Invasive Forb-annual Grass Complex

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ABSTRACT

Some rangeland plant communities previously comprised of native grasses and forbs are now co-dominated by a complex of invasive forbs and annual grasses. Management often focuses on controlling the invasive forb(s) with little regard to annual grasses. If remnant native perennial grasses are no longer present to re-occupy the site following invasive forb control, annual grasses may proliferate. We applied a variety of combinations of herbicides that would control both invasive forbs and annual grasses followed by re-seeding with desirable grasses in an attempt to restore degraded rangeland. At two sites in northwestern Montana co-dominated by spotted knapweed (*Centaurea stoebe*) and cheatgrass (*Bromus tectorum*), we tested eight herbicide treatments and six re-seeding treatments. Herbicide treatments were designed to target spotted knapweed, cheatgrass, or both species and were applied in late summer 2009. Re-seeding treatments included a non-seeded control and five grasses seeded in monoculture in late fall 2009. Very few grass seedlings were observed when plots were sampled in 2010 and 2011. We returned to one site in 2013, four years post seeding, and sampled density and biomass of established seeded grasses and cover of spotted knapweed and cheatgrass. Of the seeded grasses, tall wheatgrass (*Agropyron elongatum*) and bluebunch wheatgrass (*Agropyron spicatum*) were established and produced about 203 and 49 kg/ha, respectively, averaged across all herbicide treatments. The most effective herbicide treatment varied across seeded grass treatments but generally included aminopyralid to control spotted knapweed and imazapic to control cheatgrass. Four years after treatment, herbicide and seeding appeared to prevent reinvasion by spotted knapweed more so than cheatgrass. For example, spotted knapweed and cheatgrass cover averaged 3.7 and 4%, respectively, in non-treated plots. In plots sprayed with aminopyralid and imazapic and seeded with tall wheatgrass, spotted knapweed and cheatgrass cover averaged 1.6% and 4.2%, respectively. We recommend designing herbicide applications that target both invasive forbs and annual grasses followed by re-seeding of desirable grasses like tall and bluebunch wheatgrass to restore degraded rangeland.

Using Arbuscular Mycorrhizae to Increase Long-term Success of Prairie Restoration

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ABSTRACT

Today, native grasslands are one of the most threatened ecosystems in the United States. Native prairie habitats have been nearly extirpated from the Pacific Northwest and are the most endangered ecosystem in Washington State. Past efforts to restore these landscapes have focused primarily on outplanting containerized seedlings of native plant species important for rare butterflies, an extremely labor--- and resource---intensive approach. Long---term survivorship of these plants has been low (20---50%), suggesting that the nursery---raised plants are not well--- adapted for harsh prairie conditions (summer drought, low soil nutrients, altered soil microbial communities from non---native dominants). Mycorrhizal fungi may help to overcome biogeochemical, hydrological or microbial limitations for outplanted seedlings. In an attempt to determine effectiveness of mycorrhizal inoculation on establishment of nursery---grown plants, we outplanted seedlings of six prairie species at three different restored prairie sites that were either inoculated with a 'native' mycorrhizal mix, a 'generic' mycorrhizal mix, or un---inoculated (control). The 'native' mycorrhizal mix was cultivated from roots of eight different prairie species while the 'generic' mix was purchased from a horticultural supplier. First and second year seedlings were monitored for survivability and vigor (plant height and number of leaves). The native mycorrhizal treatment provided the greatest survival benefit, increasing survivorship by 13% to nearly 300% over the controls, depending on the species. By year two, there was no significant treatment effect on plant vigor for all but one of the species. These data suggest that mycorrhizal inoculation may be beneficial to rare prairie plants, providing enhanced field establishment rates in restoration areas. Additionally, the source of inoculum should be considered, as native---sourced inoculum offers a greater advantage than non---native sourced inoculum.

Plant Wise: Taking Action to Prevent the Introduction and Spread of Horticultural Invasive Plants in British Columbia

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ABSTRACT

Invasive species are typically introduced and spread by human action. Horticulture is a known pathway of spread for invasive plants; about 58% of invasive plants arrived in Canada as agricultural crops, landscape plants, ornamentals, and plants for wild crafting, medicinal and research purposes. Unfortunately, many of these plants have escaped cultivation and can cause long-lasting and sometimes irreversible changes to nearby ecosystems. Many can have negative environmental, social and economic impacts. Invasive plants continue to be sold in many nursery and gardening outlets across BC, and are traded as seeds, transplants or starter plants by gardening and landscaping enthusiasts.

Take Action is a leading edge provincial program developed by the Invasive Species Council of British Columbia (ISCBC) that focuses on changing the behavior of citizens so they are inspired and motivated to *Take Action* to prevent the introduction and spread of invasive species. Through this initiative, the ISCBC is working towards protecting British Columbia's environmental, social and economic interests. The Take Action program, PlantWise (PW) component, was developed to prevent the introduction and spread of invasive plants through horticultural pathways. The program combines consumer and industry resources and initiatives that are designed to (i) build consumer demand for non-invasive plants and (ii) to support the horticulture industry's transition to becoming invasive-free. The industry component of the program works to provide information and resources to assist plant growers, retailers, landscape architects and other, specifiers n transitioning to an invasive-free business through voluntary PW certification. The consumer component works towards changing gardener's behavior through public interaction at garden centers, group presentations and various gardening events The PW program was very successful in 2013; it was well received by both the public and industry alike. The 2014 PW program will focus on building a more diverse network of supporting partnerships with a greater number and variety of stewardship groups and industry partners both provincially and regionally.

Biological Control of Invasive Plants

The Potential for the Biological Control of Himalayan Balsam Using the Rust Pathogen *Puccinia* cf. *komarovii*: Opportunities for Europe and North America

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ABSTRACT

Himalayan balsam (*Impatiens glandulifera*) is a highly invasive annual herb, native to the western Himalayas, which has spread rapidly throughout Europe, Canada and the United States since its introduction as a garden ornamental. The plant can rapidly colonise riparian systems, damp woodlands and waste ground where it reduces native plant diversity, retards woodland regeneration, outcompetes native plants for space, light and pollinators and increase the risk of flooding. Current control methods are fraught with problems and often unsuccessful due to the need to control the plant on a catchment scale.

Since 2006, CABI and collaborators have surveyed populations of Himalayan balsam throughout the plants native range (the foothills of the Himalayas, Pakistan and India) where numerous natural enemies have been collected and identified. Agent prioritisation, through field observations and host-range testing has narrowed the list of potential biocontrol agents down to the rust pathogen, *Puccinia* cf *komarovii*. This paper will review work to date on the pathogen lifecycle, the impact of the pathogen on Himalayan balsam, the host-specificity of the pathogen for use in the UK and North America and on development of climate models to predict potential distribution of the pathogen in the field.

Biological Control of Yellow Toadflax, *Linaria vulgaris*: First Report of Apparent Impact of the Stem-Mining Weevil *Mecinus janthinus* in Canada

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ABSTRACT

The stem-mining weevil *Mecinus janthinus*, native to Europe, was released at numerous sites in Alberta as a biological control for the perennial crop and pasture weed yellow toadflax, *Linaria vulgaris*, between 1994 and 2002. It established and persisted at several sites, without reaching high population densities or causing apparent impact, up to the last observations made in 2002. In fall 2012, the site of a release made in central Alberta in 1996 was revisited to collect specimens for DNA analysis. It was found that toadflax densities had declined to very low levels and there were high densities of *M. janthinus* adults in the remaining stems. Further mapping and sampling in the summer and fall of 2013 confirmed that toadflax densities were very low immediately around the release site. Levels of attack by *M. janthinus* were high within about 500 m of the release site and declined to almost zero over 1000 m from the release site. These results suggest that *M. janthinus* has had an impact on yellow toadflax populations at this site, but also that natural dispersal of the agent has been very limited even 17 years after the release. This is the first report of impact of *M. janthinus* on yellow toadflax populations in Alberta, and Canada. DNA analysis confirmed that the species established at this site is *M. janthinus* and not the recently described *M. janthiniformis* which has effectively controlled Dalmatian toadflax, *Linaria dalmatica*, in British Columbia.

How Safe are Weed Biological Control Agents? A Worldwide Review of Non-Target Attack

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ABSTRACT

Non-target attack (NTA) of intentionally released organisms has long been a concern in the field of biological weed control. Even though a few individual NTA cases have received much attention in recent years, larger scale reviews on the topic are either missing, outdated or restricted to one or a few countries. One useful resource documenting NTA is Julien & Griffiths (1998), "A World Catalogue of Agents and Their Target Weeds". The recent comprehensive revision of the catalogue provided an opportunity to analyse NTA by weed biological control agents worldwide. Information in the review includes the number of agents attacking non-targets, whether attack occurred temporarily or was sustained and whether attack was predicted pre- or post-release. Examples will be provided for each scenario. We examine the extent to which NTA translates into impact on the respective non-target plant species as far as data are available. We finally discuss how to realistically incorporate NTA into post-release monitoring programs and make suggestions how to best avoid cases of unpredicted NTA in the future.

Production and Distribution of Russian Knapweed Biological Control Agents in the Western US

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ABSTRACT

In 2011, we initiated a greenhouse-based rearing program for the gall midge *Jaapiella ivannikovi* (Diptera: Cecidomyiidae), a classical biological control agent of the exotic Russian knapweed, *Rhaponticum repens* (Asteraceae). From 2011-2013, we maintained a year-round *J. ivannikovi* colony that produced midge cohorts in about four weeks. Insects were provided to researchers, and to project partners for field release from May through September. About 4,000 to 10,000 *J. ivannikovi* galls were released annually; more than 60 field releases were initiated in California, Colorado, Idaho, New Mexico, Oregon, Utah, Washington, and Wyoming. Establishment and impact are being monitored at all sites. In 2013, we initiated a greenhouse-based rearing program for a second knapweed agent, the gall wasp *Aulacidea acroptilonica* (Hymenoptera: Cynipidae). Hopefully, this colony will provide material for field release beginning in 2014.

Are Herbivore Induced Plant Defenses Important in Biocontrol?

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ABSTRACT

Predicting the efficacy of potential biocontrol agents is one of the great challenges in biocontrol. Because plant chemistry is a central factor regulating plant-insect interactions, it could provide information that can be used to better choose effective agents. One example is induced-plant responses – defenses produced by plants in response to insect feeding – which can be costly for plants to produce. Loss of fitness due to commitment of resources to defense could play a role in determining the success or failure of biocontrol. Results from research attempting to measure the costs of herbivore-induced defenses in houndstongue (*Cynoglossum officinale*) will be presented, and the potential importance for biocontrol discussed.

Misconceptions about Classical Biological Control of Weeds

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ABSTRACT

Modern classical biological control of exotic weeds aims to mitigate the negative impact of invasive weeds on biodiversity, human welfare, and economy. It implies the deliberate release of specialist natural enemies from the weed's native range to reduce the abundance of a weed in its introduced range below an ecological or economic threshold. Assessing the likelihood of non-target effects by a potential biological control agent when introduced into a new range is one of the fundamental challenges of pre-release studies in biological control projects. The long history of pre-release studies in biological weed control has significantly contributed to the development of environmental risk assessment procedures. Yet, despite its wide application across the world, discussions about the risks involved in classical biological weed control are often dominated by misunderstandings and misconceptions. By addressing some of these misconceptions, I will elaborate key questions that should be raised in public and scientific debates on the potential risks and benefits of releasing exotic organisms to control exotic invasive weeds.

Investigating the Role of Flowers and Their Scents in the Host Selection of the Seed-feeding Weevil, *Mogulones borraginis*

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ABSTRACT

Current biological weed control pre-release testing procedures rely primarily on no-choice and choice feeding, oviposition and development tests to predict the post-release host range of candidate agent species. Pre-release environmental risk assessments could be improved by examining responses of candidate agents to olfactory and visual cues, which mediate host plant finding that necessarily precedes feeding and oviposition in the field. To examine the potential of this approach, we used the seed-feeding weevil *Mogulones borraginis,* investigated for the biological control of the rangeland weed *Cynoglossum officinale,* as a study system. Using a portable volatile collection system (PVCS) and a double-stacked y-tube device (D-SYD) that we constructed, we found that female weevils strongly preferred *C. officinale* over three native congeneric and confamilial species when visual, olfactory or both cues were offered to weevils in dual-choice bioassays. Discrimination by the weevils was strongest when olfactory and visual cues were offered together. The results suggest that both visual and olfactory cues play a significant role in the host selection process of *M. borraginis*. Electrophysiological experiments, currently underway to identify specific wavelengths of light and compounds in headspace VOCs that the weevil is attracted, will be discussed.

Using Semiochemicals to Manipulate the Spatial Distribution of *Diorhabda carinulata*

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ABSTRACT

The leaf beetle, *Diorhabda carinulata,* (Desbrochers) is an introduced classical biological control agent for saltcedars (*Tamarix* spp.). Retaining the beetle on release sites has been problematic, and population growth has been slow in many areas. Negative, indirect impacts have also resulted from the agent's establishment outside targeted treatment areas in the Southwest. Manipulation of *D. carinulata* spatial distribution with semiochemicals could solve these problems.

A specialized wax based media was impregnated with *D. carinulata's* aggregation pheromone and behaviorally active host plant volatiles. Emission of these compounds from the media was evaluated using a push-pull volatile collection system and quantified using gas chromatography-mass spectrometry. Observed release rates over a week period suggest that the media is a viable option for facilitating aggregation of *D. carinulata* under field conditions.

The effectiveness of these compounds at increasing *D. carinulata* aggregation was investigated in field trials. The results of field experimentation indicate saltcedars treated with semiochemicals attracted and retained higher densities of *D. carinulata*. Treated plants not only had higher densities of adults, but also had higher densities of larvae, and showed more damage than controls. Application of semiochemicals was also able to focus low density populations of *D. carinulata* to individual plants and cause extensive damage. These preliminary results indicate that semiochemical-impregnated media could be useful in detecting, retaining, and directing populations of *D. carinulata*, and demonstrates the potential for application in other agent-weed systems.

Forty Years Later: Post-release Assessment of *Urophora cardui* and *Hadroplontus litura,* Biological Control Agents for Canada Thistle in the Western United States

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ABSTRACT

The biological control program for Canada thistle is one of the oldest in the U.S. However, relatively few studies have assessed the efficacy of those biological control agents approved for the control of Canada thistle, the stem-galling fly *Urophora cardui* and the stem-mining weevil *Hadroplontus litura*. We set up permanent study sites using the standardized impact monitoring protocol (SIMP), consisting of ten 0.125m^2 quadrats along a 20m transect at Canada thistle infestations in the State of Idaho (n = 44), Utah (n = 8), Wyoming (n = 4), North Dakota (n = 5), and South Dakota (n = 26). At each study site, four transects were set up at least 1km distant from each other and releases of either biocontrol agent alone or combined were randomly assigned among the four transects . We measured vegetation cover in five categories, Canada thistle ramet density, and assessed biological control agent abundance for each transect between 2008-2012. Biotic and abiotic environmental site variables were used to parameterize a descrete population model explaining changes in ramet density between years. Data varied greatly between study sites, years and biocontrol agent treatments. *U. cardui* and *H. litura* were widespread but occurred only at low abundances. Though proximity to the closest water source and precipitation were included in the model, current year ramet density and percent vegetation cover of other weeds had the most explanatory power for changes of Canada thistle ramet density. Biological control agent variables had no effect on the model. Our data suggest that negative plant feedback affects Canada thistle populations. Biological control, in contrast does not seem to impair Canada thistle infestations at all and thus should not be propagated.

Patterns and Impact of Herbivory by *Mogulones crucifer* on its Target Weed *Cynoglossum officinale* and the Non-Target Plant *Hackelia micrantha*

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ABSTRACT

Pre-release host specificity testing is a necessary and reliable tool for identifying nontarget species that may be used by biocontrol agents after release. However, large gaps of knowledge exist for predicting and assessing the population-level impacts of released agents on both target and used nontarget host plants. Here, we study patterns and impacts of herbivory by the root-feeding weevil *Mogulones crucifer* on its target weed *Cynoglossum officinale* and a native nontarget plant *Hackelia micrantha* in Canada. We released large numbers of *M. crucifer* into naturally-occurring patches of *H. micrantha* growing with or without *C. officinale* to simulate a 'worst case' scenario of high insect density and low target plant density, and subsequently recorded herbivory patterns and plant demographic parameters for two years on release and non-release sites. Compared to the target weed, *H. micrantha* use by *M. crucifer* was temporary, rare, mild, and limited to immediately around release points, suggesting that the nontarget plant is buffered from population-level effects by spatial, temporal and probabilistic refuges from biocontrol herbivory. *M. crucifer* did not persist 2 years after release in the absence of *C. officinale*, indicating that the insect is limited to 'spillover' nontarget use. Plant demographic data indicated that when in outbreak densities, *M. crucifer* appeared to impact *C. officinale* populations by increasing rosette mortality. While there was some evidence of impact to individual *H. micrantha* plants immediately adjacent to release points (i.e., plant death or dieback of flowering shoots), these effects did not translate to the population level. This study is a clear example of how individual nontarget use can be noticeable yet not have population-level implications, and demonstrates the importance of post-release research in weed biocontrol.

Invasive Plant Ecology

Morphological and Genetic Differentiation Among Subspecies of Medusahead (*Taeniatherum caput-medusae*): Understanding Taxonomic Complexity in the Native Range

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ABSTRACT

Invasive species are novel to a region, thus their timely and accurate identification is a critical first step in recognizing and managing the threats that they may present in their new habitats. Accurate identification of an introduced species in its new range can prove difficult however for a species that displays taxonomic complexity in its native range, i.e. consists of multiple, morphologically similar subspecies. Across its native range, *Taeniatherum caput-medusae* (medusahead) exhibits taxonomic complexity. Three subspecies have been recognized: *T. caput-medusae* ssp. *caput-medusae*, *T. caput-medusae* ssp. *asperum*, and *T. caput-medusae* ssp. *crinitum*. Only subspecies *asperum* is believe to occur in the United States, where it is now invasive in California, Idaho, Nevada, Oregon, Utah and Washington. As part of our ongoing research to better understand and manage this invasion, we are conducting genetic analyses of both native and invasive populations of medusahead. An important prerequisite to these analyses is the proper identification of the three subspecies. In the current study, plants from each native population were grown in a greenhouse common-garden, harvested at maturity, and measured using previously described morphological characters. Three characters, glume length, glume angle and palea length, were found to be statistically significant. Thus, these three characters were quite useful in assigning plants to each of the three subspecies. We found that two other characters, lemma hairs and conical cells, were less informative. Differentiation among native populations of medusahead was further assessed using a molecular genetic marker. The results of a UPGMA cluster diagram based on allozyme data, indicates that subspecies *crinitum* is genetically differentiated from the other two, some populations of subspecies *caput-medusae* and *asperum* co-occur within different clusters, and subspecies *asperum* is the most variable. Results of the analysis of multilocus genotypes are generally consistent with the UPGMA diagram (e.g., subspecies *caput-medusae* and *asperum* share six multilocus genotypes). Our findings confirm the need of such studies to better understand the taxonomic complexity that can be found in the native range of an invasive species.

Mating System Analysis of Native and Invasive Populations of Medusahead (*Taeniatherum caput-medusae*): Evidence for Pre-adaptation During Biological Invasion

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ABSTRACT

Medusahead (*Taeniatherum caput-medusae*) is an annual, highly self-pollinating grass species with a broad geographical distribution across Eurasia. The grass is invasive in six states (California, Idaho, Nevada, Oregon, Utah and Washington) in the Western United States (U.S.). Previous genetic analyses point to the Mediterranean Region, and especially Eastern Europe, as being the geographic origins for this invasion. Using enzyme electrophoresis, we determined the mating system of nine native and ten invasive populations of medusahead using two approaches: the Inbreeding Coefficient (*F*) method and progeny array analysis. These nine native populations possess at least one of the genotypes that match those detected in invasive populations from the Western U.S. Using the Inbreeding Coefficient method, both the native and invasive populations were found to be 99.8% self-pollinating, with a 0.2% outcrossing rate. Native and invasive populations were both determined to be 100.0% self-pollinating (and 0.0% outcrossing), based on progeny array analyses. These data indicate an extremely high self-pollination rate for both native and invasive populations of medusahead, and do not suggest a mating system shift is association with this invasion. Rather, high levels of self-pollination within native populations suggest that this highly selfing mating system may be a pre-adaptation contributing to the establishment success and invasion of medusahead in the Western U.S.

Reduced Mycorrhizal Responsiveness and Increased Competitive Ability in an Exotic Plant

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ABSTRACT

When relocated to new geographical ranges plants often leave co-evolved mutualists and antagonists behind. An altered biotic landscape in the introduced range may drive rapid evolutionary responses that affect how exotics interact with natives in recipient communities. We explored whether there has been an evolutionary divergence in responsiveness to arbuscular mycorrhizal (AM) fungi between native and exotic genotypes of star thistle (*Centaurea solstitialis*), and whether range-based differences in mycorrhizal responsiveness correspond with how strongly C. solstitialis tolerates competition with the North American native bunchgrass *Stipa pulchra*. When grown alone, all *C. solstitialis* plants benefited from colonization by AM fungi, but were suppressed when grown in competition with *S. pulchra* and colonized by AM fungi. However, this suppressive effect of AMF on *C. solstitialis* when competing was greater on the more mycorrhizae-responsive native European *C. solstitialis* genotypes compared to the less mycorrhizae-responsive exotic North American genotypes. Our results suggest that exotic genotypes of *C. solstitialis* have rapidly evolved a reduction in mycorrhizal responsiveness which contributes to their ability to compete with natives, and a potentially overlooked component of the evolution of competitive ability.

Using Search Dogs to find Dyer's Woad (*Isatis tinctoria*) Plants at Low Densities

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ABSTRACT

Dyer's woad (*Isatis tinctoria*) was introduced to the western US in the early 1900's. In Montana, it still occurs at densities low enough for eradication to be a plausible goal. Under the purview of Montana's Dyer's Woad Task Force, sites in seven counties in Montana with previous or current occurrence of Dyer's woad are treated and monitored. Monitoring landscapes for early incursion of invasive species, or rooting out the few remaining undesirables during an eradication effort, requires intensive manpower. Moreover, even with attentive vigilance, it can be hard to *see* these rare invaders. To this end, in 2011 dog and handler teams from Working Dogs for Conservation (WDC) started regular searches of one site in Missoula County—Mt. Sentinel—in an effort to find plants by scent in order to locate more plants than humans were able to find, and to find them before they became reproductive. Over three growing seasons, dog teams' contributions were quantified by having them search areas after human surveyors to find the plants that humans missed. In 2013, the human surveyor missed 40% of the plants found on Mt. Sentinel; no plants were seeding when found (and just 2% were flowering); and, the smallest number of Dyer's woad were found on Mt. Sentinel since recordkeeping began in 1999. Additionally, the dogs offered proof that hand digging plants was leaving root remnants behind and that new plants were sprouting from these remnants. In addition to these results we'll discuss the considerations for using dogs more widely in the control of Dyer's woad, and other plants of interest.

Overcoming Obstacles to Restoration

Herbicides Can Negatively Affect Seed Performance in Native Plants

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ABSTRACT

Herbicides are widely used to control invasive non-native plants in wildlands, yet there is little information on their non-target effects, including on native plants that are intended to benefit from the treatment. Effects at the seed stage have been particularly understudied, despite the fact that managers commonly seed native plants immediately after herbicide application. We conducted a greenhouse experiment to explore the effects of two broadleaf-specific herbicides (Aminopyralid and Picloram) on seedling emergence and biomass for 14 species (seven native and seven non-native species; five dicot and nine monocot species) that grow in dry grasslands of NW North America. For each species, we placed 50 seeds in soil-filled pots that were sprayed with a water control or one of the herbicides at one of two rates (1x and 0.01x of the recommended rate). After five weeks, we assessed seedling emergence and dry aboveground biomass per pot. At the recommended rate (1x), both herbicides significantly suppressed seedling emergence and lowered biomass. At the diluted rate (0.01x), the effect of Picloram was comparable to the effect at the recommended rate, whereas Aminopyralid had no effect. There was no difference in effects of herbicides on native versus non-native species. Although both herbicides are considered to be broadleaf specific, monocots were just as vulnerable as dicots at the recommended rate for both herbicides and at the diluted rate of Picloram. Our results show that herbicides can harm non-native and native plants at the seed stage, alike. Land managers should avoid spraying if recruitment of native species from the seedbank is a goal and should not seed directly after spraying.

Competitive Ability of Invader-Experienced and Invader-Naïve Populations: Selecting Native Plant Materials

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ABSTRACT

The need to understand rapid evolutionary responses in plants is becoming increasingly pressing as invasion by non-native species create unique biotic assemblages. An often-overlooked factor in invader-adaptation studies is variation in adaptive response at the population level. We conducted an experiment on adaptation in *Pseudoroegneria spicata* to invasion by *Centaurea stoebe.* Our specific objectives were to determine if *P. spicata* showed trait variation between ecotypes with different histories of exposure to *C. stoebe* (invader-experience types), if there were differences between invader-experience types in competitive ability, and if a population's suppression of and tolerance of *C. stoebe* were related. In a greenhouse, we grew seeds of *P. spicata* collected from eight invader-naïve and six invader-experienced populations around the Missoula valley, and seeds of *C. stoebe,* and then measured phenological traits and calculated relative interaction index (RII; a measure of competitive ability) for both species. Plants from invader-experienced populations had higher shoot biomass, but phenological traits differed more among populations than between experience types. Plants from invader-naïve populations responded differently to competition with *C. stobe* than did invader-experienced populations, with invader-naïve populations having lower growth and biomass when grown in competition. Adults from invader-experienced populations were more tolerant (higher RII) of *C. stoebe* than were plants from invader-naïve populations. Suppression of *C. stoebe* by *P. spicata* did not vary by experience type, but did vary among populations. Tolerance of competition from *C. stoebe* significantly predicted a population's suppression of *C. stoebe*, suggesting that the both measures of competitive ability are linked. While plants from the invader-naïve group were more impacted by competition, population appears to be a better predictor of competitive ability. Increased restoration success could be achieved by using materials from specific populations (rather than generalizing by invader experience or species) that exhibit traits related to competitive ability.

Use of Soil Inoculum in Restoration: Risks and Benefits

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ABSTRACT

Using soil inocula, such as commercial mycorrhizal fungi products, can produce mixed results in restoration. Many factors may affect the outcomes of using such products, such as characteristics of the site and native and invasive plant species, as well as inoculum type, quality, and application method. An overview of considerations for the use of inocula in restoration will be presented, with an emphasis on arbuscular mycorrhizal inoculum.

Results from a field study will also be discussed. At a grassland mine restoration site, the effect of commercial mycorrhizal inoculum on aboveground biomass of a grassland community was compared with using local native soil as a source of inoculum and a control. In addition, greenhouse-grown seedlings of a native grass (*Stipa pulchra*) were subjected to commercial mycorrhizal inoculum, local soil, or control treatments, and then transplanted into field plots. When inocula were applied directly to field plots, the local soil treatment tended to increase total community biomass, but effects on native versus non-native species differed throughout the three years of study. When *S. pulchra* seedlings were inoculated during initial growth and then transplanted into the field, the local soil treatment resulted in greater aboveground biomass and N content of *S. pulchra* relative to controls. The commercial inoculum treatment resulted in increased mycorrhizal colonization of *S. pulchra* roots relative to controls, but did not significantly affect biomass of *S. pulchra* or grassland community biomass. Findings indicate that at this site, use of local soil as an inoculum was more effective in increasing plant biomass than the commercial product used, but in order to increase native grass biomass inoculation of transplanted plugs was necessary.

Selective Granivory by Native Seed Predators Can Enable Exotic Invasion and Impede Restoration Efforts

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ABSTRACT

Before germinating, growing to maturity, reproducing, and dispersing, plants must first survive the seed stage. However, surviving the seed stage can be strongly limited by granivory. Since generalist granivores often prefer native species over invasive species, disproportionate survival of invasive seeds may favor the establishment of invasive species and profoundly affect community assembly, possibly maintaining and even facilitating plant invasions. Disproportionate seed predation may also limit the survival of seeds used in restoration efforts, potentially undermining the effectiveness of restoration seeding. Here, we review evidence that native granivores from invaded systems in North America 1) often prefer seeds from natives over seeds from invaders, 2) can enable exotic invasion via preferential granivory, and 3) can impede restoration efforts. Finally, we suggest that reseeding efforts could benefit by considering ways to ameliorate or offset potentially detrimental effects of granivory. Such considerations might include 1) increasing reseed density, 2) excluding granivores, or 3) reducing competition with other exotic species.

Building Soil Protection and Improvement into Your Restoration Plan

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ABSTRACT

Healthy, functioning soils are the foundation of successful revegetation and restoration plans, but are often neglected during project planning and implementation. Consideration of project objectives, desired future conditions for vegetation, and reference site conditions should drive strategies for soil conservation and enhancement. Early integration with planners and engineers is essential to ensure soils and revegetation objectives are considered in design and implementation phases. The importance of landscape setting (native soils and geomorphology), limiting factors analysis, topsoil salvage and organic waste utilization, development of contract specifications, and on-the-ground oversight will be addressed.

Restoration and Community Assembly of Annual Grass Invaded Shrub-Steppe: Effects of Modified Dispersal, Propagule Pressure, and Water Availability

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Jeremy J. James

University of California

ABSTRACT

Dispersal limitation is argued to drive restoration and assembly of seeded perennial grasses in annual grass infested ecosystems; however, the affects of seed arrival, seeding frequency, and seed performance in differing soil resource environments on perennial grass recruitment is not quantified in infested annual grass shrub-steppe ecosystems. To assess these effects, we created a field experiment consisting of 288-1 m^{-2} plots in an annual grass dominated shrub-steppe ecosystem in eastern Oregon. We tested the effects of modified perennial grass seeding timing and frequency, adding water, and varying annual and perennial grass propagule pressures on annual and perennial grass seedling density through time and final biomass. We found that perennial grass density and biomass was highest when perennial grass propagule pressure was 2500 seeds m^{-2} or higher and when half of the perennial grass seeds were seeded in November and the remaining half were seeded in February. We also found that when annual grass propagule pressure exceeded 1500 seeds m^{-2}, perennial grass density and biomass decreased, regardless of perennial grass propagule pressure. Higher water availability initially facilitated perennial grass establishment but watering only produced higher density two-years following seeding when annual grass propagule pressure was low. Consequently, when annual grass propagule pressure exceeds 1500 seeds m^{-2}, perennial grass recruitment will be low regardless of perennial grass propagule pressure. However, at low annual grass propagule pressures, increasing perennial grass propagule pressure and seeding frequency and adding water will increase perennial grass recruitment.

Aquatic Invasive Plants

Optimizing the Use of Clipper Herbicide

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ABSTRACT

Vegetation management in water bodies can be challenging, which often makes it difficult to maintain water in pristine condition. Clipper herbicide contains the active ingredient flumioxazin and has been developed by Valent Professional Products for use in aquatics to assist in the management of unwanted vegetation. Field applications of Clipper in 2012 displayed limitations, yet have proven to be a valuable tool to manage unwanted vegetation in water bodies and provide an alternative option for controlling difficult to manage plants such as Fanwort (*Cabomba caroliniana*) and Watermeal (*Wolffia* spp.). Treatments of Clipper throughout the country have provided an opportunity to monitor and evaluate the performance of this herbicide when applied under a wide array of conditions. Surface as well as submersed applications of Clipper were monitored for activity on specific vegetation, movement from the treatment area, and persistence in the water column. Few contact herbicides have been introduced in the aquatics market that displays selectivity on floating and submersed weeds. Data taken from these trials will be shared that confirms Clipper is a selective herbicide with a short-life in the water column that can be used as part of a successful management strategy for selected unwanted vegetation in Midwestern water bodies.

From Identification to Operational Scale Eurasian Watermilfoil Control, 2007 to 2012 – Noxon Rapids Reservoir, Montana

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ABSTRACT

Eurasian watermilfoil (*Myriophyllum spicatum)* was first identified in Noxon Rapids Reservoir, Montana in 2007. Noxon Rapids Reservoir is located in Montana on the Clark Fork River in the upper Columbia River Basin. The reservoir is a run of the river system that required understanding of water release management for power generation and other factors to support developing a management plan for Eurasian watermilfoil (EWM). Management efforts began after a positive identification of EWM presence in 2007 that included trials and demonstrations in 2009 and 2010 led by the US Army Corps of Engineers who coordinated contact and exposure time (CET) evaluations with liquid formulations of triclopyr, endothall, and diquat; the GeoResources Institute (GRI – Mississippi State University) who carried out aquatic vegetation identification and GIS/GPS based vegetation mapping for efficacy evaluation purposes; and Clean Lakes, Inc., who provided application expertise and program support for the liquid herbicide applications with Littoral Zone Treatment Technology (Littline®). Cooperators included Avista Corporation, Sanders County, MT, Montana State University Extension, and the Noxon Cabinet Shoreline Coalition. An overview of the 2009-2010 research evaluations and the 2012 operational scale treatments will be provided.

Managing Eurasian Watermilfoil in the Lower Clark Fork River System, Montana

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and Kurt D. Getsinger

US Army Engineer Research and Development Center, MS

ABSTRACT

Eurasian watermilfoil (*Myriophyllum spicatum* L.) was first found in Noxon Rapids Reservoir and Cabinet Gorge Reservoir in 2007. Whole-lake surveys were done in 2008, and repeated in 2009, 2010, and 2013, using a point intercept method. The surveys found 247 acres of Eurasian watermilfoil in Noxon Rapids and 78 acres in Cabinet Gorge. Since Noxon Rapids is the upstream reservoir of the two, and is more heavily utilized for recreation, management initially focused on Noxon Rapids Reservoir. Innovative management approaches were implemented for dense beds and channel-margin infestations, to improve selective management under conditions of high water exchange. Treatment efficacy, as evaluated by point intercept methods, indicated that treatments reduced Eurasian watermilfoil frequency by 80% by 5 weeks after treatment (WAT), and 94% by 52 WAT. While some level of native plant injury was observed at 5 WAT, all plots had increased native plant frequency and diversity by 52 WAT. By 2013, dense Eurasian watermilfoil was reduced to 97 acres, and 5% of the littoral zone points. Meanwhile, little management has been done on Cabinet Gorge Reservoir, due to budgetary limitations, and the acreage of dense Eurasian watermilfoil has increased to 205 acres and 18% of littoral zone points.

Eradication of Eurasian Watermilfoil in Beaver Lake, Montana; a Success Story: Lessons Learned and Ongoing Issues for Aquatic Weed Management in Montana

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ABSTRACT

Beaver Lake is a small (144 acre) lake in Northwest Montana that is lightly used for recreation. Eurasian watermilfoil was discovered in Beaver Lake in September 2011. A multi-jurisdictional team was assembled to rapidly respond and develop a long term strategy for the infestation. Within two weeks a whole lake survey was conducted and bottom barriers were placed over the only known patch. A strategy was developed and implemented in the summer of 2012 that encompassed multiple infestation and response scenarios. Snorkel surveys of the littoral zone identified two additional patches and scattered plants in one area of the lake. Diver dredging was determined to be the best management option. Twenty three pounds of dried EWM was removed in 2012. In 2013, less than 5 pounds of dried EWM were removed. Diver dredging will occur in 2014 and it is estimated that EWM will be eradicated in Beaver Lake by 2015.

The effort to address this infestation highlighted ongoing invasive aquatic plant management issues in Montana. The traditional terrestrial weed management structure and response is not easily applied in aquatic scenarios, our ability to respond rapidly is currently limited and questions on who is responsible and in charge still remain. This eradication effort was a success by working as a team collaboratively and collectively to find a solution.

Aquatic Herbicide Chemistries: a Review of Modes-of-action and Best Management Practices for 2014

Andrew Z. Skibo

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ABSTRACT

The aquatic market continues to press for registration of new herbicides exhibiting activity on a number of the most important and developing invasive aquatic weed species such as *Eichornia crassipes*, *Hydrilla verticillata*, *Butomus umbellatus*, and many others. Unfortunately, many potential candidate molecules familiar to researchers in the terrestrial arena are too toxic for aquatic use (diuron, trifluralin, etc.), while others are off patent (dicholbenil, simazine, etc.), which greatly reduces the potential for any one chemical company to proceed in incurring the high Federal registration costs[1].

Currently, there are approximately 300 herbicides registered in the US which function across 26 specific modes of action . Of the 14 registered for aquatic use, only 6 general modes of action are represented (photosynthetic inhibitors, amino acid/ protein synthesis inhibitor, cell division/ growth inhibitors, cell membrane disruptors, pigment synthesis inhibitors, and growth regulators). Since the turn of the millennium, 7 new herbicides have been registered for aquatics: triclopyr, imazapyr, carfentrazone, penoxsulam, flumioxazin, and bispyribac sodium. While these new actives generally have favorable ecotoxicity profiles, the majority all have a single site of action in plants, which may increase the possibility of resistance development to occur.

A cursory review of the literature published in 2013 alone denotes the growing presence of resistant weed biotypes across the world. It is estimated that there are currently 407 herbicide resistant weed biotypes globally, represented across 221 species (130 dicots and 91 monocots). Further, weeds have evolved resistance to 21 of the 26 known herbicide sites of action and to 148 different herbicides. Approximately 70 of these species occur in the United States, with most occurring in agricultural systems (www.weedscience.org).

A review will be presented of the currently registered aquatic and riparian herbicides. For discussion: mode-of-action (MOA) classes, active ingredient and formulation characteristics, successful use patterns, and suggested best management practices for the upcoming 2014 water season.

1 **Koschnick, T.J., Haller, W.T., and M.D. Netherland, M.D.** 2006. Aquatic Plant Resistance to herbicides, Aquatics magazine, Volume 28, No. 1

Clean, Drain, Dry: Taking Action to Prevent the Introduction and Spread of Aquatic Invasive Plants in British Columbia

Jodi Romyn, Gail Wallin

Invasive Species Council of BC (ISCBC),

ABSTRACT

Invasive species are typically introduced and spread by human action. In 2011, baseline data was collected on the primary pathways of invasion in British Columbia. The results indicated boating as being a key vector of aquatic invasive species (AIS) introduction and spread. Take Action is a leading edge provincial program developed by the Invasive Species Council of British Columbia (ISCBC) that focuses on changing the behavior of citizens so they Take Action to prevent the introduction and spread of invasive species. Through this initiative, the ISCBC is working towards protecting British Columbia's environmental, social and economic interests.

The Take Action Clean, Drain, Dry (CDD) Program was developed to prevent the introduction and spread of aquatic invasive species, such as aquatic plants zebra and quagga mussels, through recreational pathways, specifically boater activity. The CDD program teaches responsible, preventative actions towards the spread of AIS by using messaging and resources across the province that is consistent with messaging in Alberta and in our neighboring states. The CDD goal is to use the power of positive-based Community Social Marketing to change the behavior of boaters. This approach inspires and motivates boaters to commit to cleaning, draining and drying their boats and equipment before entering a water body. This approach proved to be a strong driver of behavior change in the program. The CDD message was also communicated to stewardship and youth groups through delivering presentations and attending relevant community events After 2 successful years of on the ground work the 2014 CDD program will continue to focus on delivering the CDD message by building a network of aquatic ambassadors across BC.

Invasive Plant Mapping & Modeling

Plant Community Susceptibility and Invasive Plant Dispersal Models Both Contribute to Early Detection of Invasive Plants

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John Wallace

Penn State University, State College, PA

ABSTRACT

Invasive plant species management generally can fall into categories of prevention, early detection and removal, and finally long-term management. Early detection is a daunting task because of extensive landscapes and often difficult terrain within the intermountain west. Plant community susceptibility to invasion can shape a strategy for detection that focuses on areas at greatest risk to invasion based on their susceptibility and their proximity to existing infestation or their proximity to transportation routes. Utilizing remote sensing data, we can estimate the biomass of plant communities, one indicator of susceptibility to invasion. We also use remote sensing data to obtain environmental data that relate to physiological limits to a species distribution such as growing degree days, direct solar radiation, and snow-free period. When used in conjunction with current invasive plant distribution data, we can create models that predict which plant communities are at risk to invasion by a specific plant species. Currently our approach has been used to conduct invasive plant surveys in Idaho for rush skeletonweed and leafy spurge. Both of those efforts also include a dispersal component where we prioritize susceptible communities that fall within likely dispersal patterns for each of the species. The objective of the presentation will be to provide a brief background on the approach and then focus to implementation through ongoing projects to detect invasive plant species.

Practical Applications of GIS in EDRR

Jed Little

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ABSTRACT

Field mapping, GIS analysis and the ability to produce highly detailed, accurate field maps have become an integral part of the Missoula County Weed District's effort to control high priority noxious weed species. This presentation will highlight a number of GIS driven new invader control projects, share the techniques we have developed for efficient, accurate field data collection and discuss how ArcPAD has improved efficacy in new invader control.

Growing from an Inventory Program to a Fully Integrated EDRR Program on a Local Level - Twenty Years of Experience

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ABSTRACT

Twenty years ago Fremont County Weed and Pest Control District (FCWPCD), decided to move what inventory data that had been gathered on paper maps into a digital format. Once this was accomplished, FCWPCD looked into methods of on the ground weed inventory to create a more accurate understanding of the extent of the noxious weed problem. The first step was setting up the spray crews with GPS capabilities to record not only the infestations as they spray but the travel logs to show the extent of the area they looked for weeds. It soon became obvious there were numerous areas in the county where no one had been to check. The decision was made to hire a full time mapping technician to conduct a structured weed inventory of the county. Between the spray crews and the mapping crew, the inventory data gathered located infestations that were high priority and needed to be considered for rapid response. This led to a spray crew being dedicated to treatment of these high priority infestations. To date the now EDRR program has an Assistant Supervisor, a fulltime mapping technician, a fulltime spray person, and two seasonal EDRR crews. This program has been integrated into and become an integral component of FCWPCD's weed management plan.

Observations on the Biological Control of Dalmatian Toadflax in Oregon

Alex Park and Eric Coombs

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ABSTRACT

Dalmatian toadflax (*Linaria dalmatica*) has become a prolific invasive plant of rangelands in the State of Oregon since its arrival in the early 20th century. Dalmatian toadflax impacts an estimated 350,000 acres primarily in the high desert ecosystem east of the Cascade Mountain range. In 2001, a biocontrol release program using the stem-boring weevil *Mecinus janthinus* was implemented to reduce densities of Dalmatian toadflax and improve ecological integrity. In our post-hoc observational study, we found that *M. janthinus* had become widely established on toadflax infestations independently of human dispersal, and the weevil had reduced toadflax density relative to year of release. We used historical biological release and monitoring data, and a limited state-wide survey of Dalmatian toadflax and *M. janthinus* in 2013. The results showed that *M. janthinus* has reduced estimated Dalmatian toadflax densities at former release sites from an average of $9.45 \pm 1.34/m^2$ to $5.5 \pm 1.1/m^2$. Across release sites, there was an average 50%, and maximum 98% reduction in plant density. It was also found that the weevil has naturally migrated beyond their original release sites with the median distance from release at 1.5 km and maximum of 60 km. Results from a sentinel site showed that toadflax rebounded following 90% control, however the weevil was able to track the outbreak and re-suppress the infestation. Our results indicate that the biocontrol of Dalmatian toadflax is an emerging regional success and that redistribution of the weevil is no longer necessary.

Regional Perspectives

Idaho's Aquatics Program

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ABSTRACT

Idaho has an active aquatic invasive species treatment, survey and prevention program. Treatments of aquatic plants have run into some interesting challenges in 2013 and new strategies are being employed for treatment and control. State-wide survey for invasive species has identified several new species as well as the expansion of some existing species populations. Idaho's prevention program is primarily targeted at trailered watercraft to prevent the movement of aquatic invasive plants, snails and mussels. The movement of zebra and quagga mussels is of particular concern and focused efforts are being made to prevent their introduction into the region.

The University of Georgia Center for Invasive Species & Ecosystem Health: Current and Future Directions of Resources for Invasive Species EDDR, Management and Education

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ABSTRACT

The Center for Invasive Species and Ecosystem Health was established in 2008 as a collaborative effort between Warnell School of Forestry and Natural Resources and the College of Agriculture and Environmental Sciences. The Center develops, consolidates and disseminates information and programs focused on invasive species, forest health, natural resources and agricultural management through technology development, program implementation, training, applied research and public awareness. Center supports and provides outreach education and training for landowners, foresters, wildlife and other natural resource professionals and the general public. The web resources and Information Technology (IT) products, that provide readily accessible information and tools for users, are comprised of four inter-related information technology systems.

Biocontrol Collaboration in the Pacific Northwest

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Joseph Milan

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ABSTRACT

Invasive plants in the Pacific Northwest continue to spread across jurisdictional boundaries, making control efforts challenging for individual agencies and landowners. Management success can be better achieved through strong collaboration. Cooperative Weed Management Areas (CWMAs) have gained in popularity because landowners and managers work together to achieve common goals. Biological control is no different. Without cooperative efforts amongst collaborators, we would not share the successes we have today as a biological control community. Idaho, Oregon, and Washington share many target weed species. Our collaboration has increased the number of agents available for collection and redistribution. In addition, this partnership has led to more robust research efforts on several projects. This presentation will discuss projects where collaboration has resulted in better implementation of biological control for landowners and managers in the Pacific Northwest.

Flowering Rush Symposium

Welcome and Overview of Flowering Rush Biology

Tim Miller

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ABSTRACT

This symposium was sponsored by a grant from The Western Integrated Pest Management Center and is aimed at thoroughly discussing what we know and do not know about flowering rush (*Butomus umbellatus*) in North America. This species is a vigorous aquatic perennial that spreads primarily by lateral growth of rhizomes, by rhizome fragmentation, or by corm-like bulbils produced on rhizomes or in the inflorescences. Plants root in the mud and generally emerge from standing water near the shore, although fully submerged forms also exist. Maximum water depth is about 3 m for the species. Leaves are pith-filled, triangular in outline, up to about 1 m long, and are slightly twisted when viewed from above. Flower stems form in early to mid-summer, terminating in a cymose umbel bearing 20 to 50 light pink flowers. Flowers consist of three pink sepals and three slightly larger pink petals, nine stamens, and six carpels in which some 200 ovules are ripened. Flowers and viable seeds are primarily produced on sexually fertile diploid plants; triploid plants are sterile and rarely flower. Symposium sessions will focus on distribution, biology, and control of this newly-emerging weed species.

Flowering Rush in Washington: Distribution and Control Trial Results

Jenifer Parsons

WA Dept. of Ecology, 15 W Yakima Ave, Suite 200, Yakima, WA 98902

Tim Miller

Washington State University, 16650 State Route 536, Mount Vernon, WA 98273

Laurel Baldwin

Whatcom County Noxious Weed Board, 322 N. Commercial St. Suite 110, Bellingham, WA 98225

ABSTRACT

Flowering rush (*Butomus umbellatus*) is currently found in several major rivers, one lake and a few small ponds in Washington State. The plants growing in deeper water of the river systems do not lend themselves to chemical control due to water flow. In those areas we have tried hand pulling, both from shore and with divers, and some use of bottom barriers with discouraging results. Field control trials of glyphosate, imazapyr and triclopyr on emergent plants have shown that imazapyr provided the best control when at least 2 ft of leaf was above water. We also conducted field control trials of submersed growth with 2,4-D, triclopyr, imazamox and diquat. Results showed repeated treatments with diquat reduced biomass and plant abundance.

Flowering Rush Expansion in Idaho

Thomas Woolf

Idaho State Department of Agriculture, Box 790, Boise, ID 83701

ABSTRACT

Idaho has observed a rapid expansion of flowering in recent years. First Identified in a small population in Lake Pend Oreille in 2007, it has now expanded throughout the lake and densities are now beginning to interfere with recreation in populated areas. Chemical and mechanical treatments have been conducted but results have been disappointing. Flowering rush in Southern Idaho appears to not be expanding downstream however it has recently been discovered 30 miles upstream of previously known populations. Research plans are moving forward for treatment trial projects in 2014.

Flowering Rush in Detroit Lakes: From Research to an Operational Management Program

John D. Madsen

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ABSTRACT

Flowering rush (*Butomus umbellatus* L.) is a relatively new invasive plant to North America, first found in the 1970's. While a nuisance problem for Detroit Lakes over four decades, it is little-known elsewhere. Starting from a research program in 2010 to understand the biology and ecology of flowering rush and experiment with management techniques, in 2012 we were able to demonstrate an operational-scale program of management, achieving over 90% reduction in nuisance growth and reducing rhizome buds by 80%. Because flowering rush is a perennial, the problem is not solved by one year of treatment, but we do have program that is effective at both reducing nuisance growth and reducing the ability of flowering rush to regrow the following year. Further research and monitoring will safeguard the diversity of native plant growth and fish habitat, and provide other alternatives for management in the future.

Flowering Rush Habitat Suitability for Introduced Fish & Macroinvertebrate Community Changes

Peter M. Rice

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Virgil Dupuis and Jerome O'Brien

Salish Kootenai College,

David Stagliono

Montana Natural Heritage Program

ABSTRACT

Flowering rush does not simply displace native aquatic vegetation. It colonizes previously unvegetated portions of variable drawdown zones. These monotypic colonies in previously open water littoral zones are inducing cascading ecosystem and trophic effects. Higher order impacts include alteration of sediment transport and deposition, and formation of new habitat favorable to introduced fish and disadvantage to native trout and salmon. The species composition (fish and aquatic macroinvertebrates) of flowering rush infestations is ecologically and statistically significantly different than that of native vegetation and open water communities.

Sonar PR and Renovate 3 Combinations for Flowering Rush Control in Lake Pend d'Oreille

Andrew Z. Skibo

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ABSTRACT

Flowering rush (*Butomus* umbellatus), a perennial dichogamous monocot of the monogeneric Family *Butomacea,* and is related to the true rushes (Family *Cyperacea*) in name only. This aquatic forb species has spread as a result of escape from cultivation in the ornamental trade and is now found across 17 of the Northern United States and nearly all of the Canadian Provinces. First documented on Flathead Lake, Montana in 1964, the spread of Flowering Rush now encompasses thousands of acres across the Pacific Northwest in habitat that is considered essential for the spawning of a number of *Salmonid* species.

Previous mesocosm and field studies examining both preëmergent, foliar, and in-water herbicide applications have examined the efficacy of a number of aquatically registered herbicides such as imazapyr, imazamox, fluridone, triclopyr, 2,4-D. endothall, diquat. Systemic herbicides such as fluridone, imazapyr, and imazamox applied either as a preëmergent, bareground application during periods of system drawdown or applied in-season as in-water applications have shown excellent results the season of application into the following growth season while contact herbicides such as diquat, flumioxazin, endothall, and diquat have given variable results on foliar materials and demonstrated little effect at reducing below ground biomass.

Based on these results, a field trial was initiated on Lake Pend d'Oreille, Idaho in 2013 to further quantitate the single and sequential season efficacy of granular fluridone (Sonar® PR) and triclopyr (Renovate® OTF) combinations on emergent and below ground biomass reduction. Combined application of Sonar and Renovate granular formulations was made August 1, 2013. Dissipation of initial applications was monitored 6, 12, 24, 48, 72 hours after treatment (HAT), 336 (14DAT), 672 (28DAT), and 1008 (42DAT) days after treatment (DAT). A repeat application of Sonar PR pellets was made August 21, 2013 to further maintain fluridone concentration exposure time and water samples were further collected at two week intervals until the lake was drawn down to the point of site inaccessibility. Monitoring of triclopyr (Renovate) concentrations showed effective exposure out to 72HAT with a building concentration of fluridone (Sonar) that was maintained until the end of monitoring period at time of site scheduled dewatering in October. Efficacy of the combination protocol was assessed through pre-treatment point-intercept survey, species biodensity ratings, hydroacoustic survey, and a repeat hydroacoustic survey on day of the repeat application. Plans call for both spring and late summer 2014 re-assessments. The preliminary results of post-treatment monitoring and initial assessments will be presented and discussed.

Small Area Renovate Max G, Aquathol Super K, and Diquat Treatments of Flowering Rush

Steve Fleming

Archibald Lake, Wisconsin W292 N6973 Dorn Rd., Hartland, WI WI 53029

ABSTRACT

To date most flowering rush research has been done in either bucket trials or larger multi-acre lake trials. The Archibald Lake Association, in northeastern Wisconsin, has been seeing positive results in small littoral zone trials. This presentation will discuss the results from the past three years of trials using Renovate Max G, Diquat, and Aquathol Super K.

Prospects for the Biological Control of Flowering Rush, *Butomus umbellatus*

Hariet L. Hinz and Patrick Häfliger

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ABSTRACT

Flowering rush (*Butomus umbellatus*) is an aggressive invader of freshwater systems, which is becoming an increasing problem in the Midwestern and western states. Since no effective control methods are currently available, a biological control project was started in spring 2013 and CABI in Switzerland subcontracted to conduct surveys on potential insect agents. A literature search has so far revealed two fungal pathogens and 18 insect species that are recorded to develop on flowering rush in Europe. Four of these species, two weevils and two flies, are potentially monophagous on flowering rush and are expected to damage the plant. All are described to feed in the leaves and stems of flowering rush. Several field trips were conducted to northern Germany and one to the Czech and Slovak Republic with the aim to find one of the two weevil species (*Bagous nodulosus*) and to collect any other phytophagous species found on the plant. We frequently found larvae and pupae of three fly and two moth species and adults and larvae of a reed beetle in the genus *Donacia.* All reared or collected adult specimens are currently being sent off for identification. A total of 54 *B. nodulosus* were found, taken back to Switzerland and observations on its biology and behavior started. Adults make characteristic feeding marks on the leaves, often at the leaf tip, which makes it relatively easy to verify their presence in the field. Eggs are laid into the leaves, either above or below the water level. Hatching larvae are very mobile and move, mostly externally, down into the leaf bases where they feed during a few weeks. Some larvae were also found damaging parts of the rhizome. Our aims for 2014 are to establish a rearing colony of *B. nodulosus* at CABI and to start with host-specificity tests. A test plant list was established and a first shipment of plants made to Switzerland. In addition, we will continue with surveys and will try to start work on one other potential agent. Based on these very first results, prospects for the biological control of flowering rush are promising.

Flowering Rush Biocontrol: Future Funding and Research Needs

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ABSTRACT

Flowering rush, *Butomus umbellatus* L., is an aggressive invasive plant that rapidly colonizes freshwater aquatic systems. It is becoming an increasing concern in many states and provinces and is poised to become a substantial problem in many major waterways, despite ongoing eradication efforts. Although appropriate chemical and mechanical control methods continue to be explored, they have thus far been relatively ineffective, creating concerns that the flowering rush populations will continue to expand and spread without restriction. In looking for possible control methods, we are taking a proactive approach by pursuing potential biological weed control agents and have formed the Flowering Rush Biocontrol Consortium to coordinate the project. In 2013, CABI began foreign exploration with funds acquired from Montana, Washington and British Columbia agencies. Several insects, including a leaf-rhizome beetle *Bagous nodulosus* Gyllenhal, were collected. A preliminary test plant list was developed and several species were shipped for host-specificity testing in 2014. Research on the impacts of flowering rush and input into the final test plant list are needed to strengthen the overall success of the project. In addition, future funding is critical to continue the project past 2014. Avenues for funding and research needs will be discussed.

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