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Biological Control of Yellow Toadflax (*Linaria vulgaris*) (L.) (Scrophuliaraceae): Opportunities and Constraints Affecting the Reclamation of Rangelands in the Western United States

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Introduction

Linaria vulgaris (yellow toadflax) is a problem weed affecting the stability of rangeland ecosystems in the western United States. All *Linaria* spp. are moderately toxic to livestock (Polunin, 1969), leading cattle to avoid stands of toadflax, creating a consequential loss to grazing (Jeanneret & Schroeder 1991). Yellow toadflax can displace existing plant communities and associated animal life, leading to an increased disruption in the equilibrium of rangeland ecosystems. Loss of native forage can also impact big game species, resultant in lower numbers of selective grazers (Grubb et. al. 2001).

L.vulgaris ('yellow toadflax') is a perennial weed with circumpolar distribution (Hartl, 1974). *Linaria vulgaris* is a competitive weed species in horticultural and agronomic crops in Canada, Europe, New Zealand, Russia, and in the U.S. (Holm et al. 1979). In the United States and Canada, three species of toadflax are considered noxious weeds: yellow toadflax (*Linaria vulgaris*), dalmatian toadflax (*Linaria dalmatica*) and narrow-leaved dalmatian toadflax (*Linaria genistifolia*). *L.vulgaris* was introduced into North America in the mid-1600s as an ornamental perennial (Darlington 1859) and as a folk remedy (Fernald 1905, Rousseau 1968). *L.vulgaris* soon escaped from gardens to infest farmland, pastures and rangeland across the central and western U.S. and parts of Canada. *L. vulgaris* is common in eastern North America, but can be found in many areas of the west. Western states most affected include: Idaho, Montana, Oregon and Washington (Carpenter and Murray 1998).

Traditionally, managers have controlled *Linaria* with herbicide, but also have attempted prescribed burning and intensive grazing. None of these tactics have been effective, and in fact, have often resulted in increased regrowth. *Linaria* is ubiquitous, which contributes to its potential to reinvade after treatment. Typically, *L.vulgaris* prefers dry, open habitats such as roadsides, railway tracks, clear cuts and old fields (Hartl, 1974), which can all harbor populations outside of control areas. Hybrids between yellow toadflax and dalmatian toadflax (*Linaria dalmatica*) can be produced in the laboratory, so natural occurrence of this hybrid in the field further complicates restoration efforts (Saner 1994).

Because traditional control methods were not successful, managers became interested in using biocontrol. The overall purpose of biological control is not eradication, but reduction in weed densities and the rate of weed spread to an acceptable level (Wilson and McCaffrey 1999). Biological control is most effective in dense weed infestations over large areas when considering long-term cost of chemical control, human hours and cost to maintain, operate and move machinery. In situations where *Linaria* spp. have impacted ecosystem health and where large infestations are beyond management, biological control is a viable option and can help reduce infestations to manageable size. Compared to burning and herbicides, insect agents can control inaccessible infestations and do not require recurrent management actions. Hence, the use of insect herbivory as a form of reducing spread in dry conditions, may help to turn a management nightmare into a realistic management option, especially in situations where cultivation or prescribed burns may not be applicable.

However, biological control may not be possible or needed in some cases. For example, if *L.vulgaris* populations are small (more or less under control), and the toadflax seed bank has already been reduced by years of repeated spraying, the application of insects to a site would be inappropriate. In addition, the occurrence of hybrid *Linaria* may also limit effectiveness of biocontrol. Biological control should be carefully evaluated on a case-by-case basis and thought of in terms of the following questions: How will introducing this insect impact other non-intended species? What are the habitat requirements of the insect? Will the introduction of the insect have short-term or long-term impacts upon the affected ecosystem? Is there a management plan if biocontrol methods have unintended consequences? In order to answer these questions, a management model has been developed to optimize weed control strategies for *Linaria*.

Weed Management Model

An integrated weed management model is a system for the planning and implementation of selected methods of management for preventing, containing or controlling undesirable plant species or group of species using all available strategies and techniques. Together these strategies and techniques are economically and environmentally more effective than any single option. All control methods are available and are prescribed on a species/infestation specific basis. Elements of integrated management include: education/awareness, prevention early/detection, inventory, treatment (including physical, biological, cultural and chemical methods), and monitoring. The State of Idaho Department of Agriculture, responsible for weed management in rangeland ecosystems, uses the Integrated Weed Management Model to plan for *Linaria* control.

The Integrated Weed Management (IWM) Model is a holistic, systems approach to weed management (Idaho State Department of Agriculture, internet resource). The model attempts to predict the management elements that will best limit a weed's impact and spread. All elements are considered together: strategies such as early detection are modeled along with treatment "tools" such as physical, mechanical, biological, herbicides, cultural management practices and the restoration of weed impacted lands. So, the IWM can identify the logical role for biocontrol, as part of the overall weed management approach. Depending on the seriousness of the infestation, biological control may help bring large-dense infestations to a level where other techniques are used simultaneously. The model is one of the few ways that managers can develop control programs based on very different weed strategies (i.e., policies, herbicides, biocontrol) and avoid focusing on only one.

This model has been used to develop weed control strategies for the Upper Payette River Watershed in Idaho. The area under management is titled Upper Payette Cooperative Weed Management Area (CWMA). Currently, infestations of *Linaria* spp. have become a major problem in two areas within the CWMA, covering a total of 2,000 hectares. The tools identified by the model, now being used to prevent further infestation include: 1) an exchange of certified weed free hay for non-certified hay used by hunters to bait game, 2) pest applicator workshops, and 3) spreading the word at every opportunity. Each known infestation in the watershed was prioritized, and then treated with a contain, control, manage, or eradicate strategy, as appropriate for that infestation (Upper Payette Cooperative Weed Management Area 2002 Year End Report, internet resource). New signs were made and placed in strategic locations to increase weed awareness.

In one specific location, 1,400 hectares of toadflax had been targeted for standard treatment and biological control. Insects selected for use by the State of Idaho Department of Agriculture include: *Calophasia lunula, Brachypterolus pulicarius* and *Mecinus janthus*. The CWMA containing the infestation of *Linaria* spp. will be monitored for changes in 2003 after applications are made in the fall of 2002.

Similar biological control methods are being used to control epidemic infestations of dalmatian toadflax and yellow toadflax in the Boise Basin CWMA, Idaho. Biological control is being used here where the extent of infestation is over the 1,200 – 2,000 hectare size, and standard management techniques such as chemical applications and mowing (Boise Basin Cooperative Weed Management Area Accomplishment Report 2002, internet resource). A portion of the basin includes part of Oregon, and in that portion alone over 12,000 hectares of land was recorded in 1990 as infested by toadflax. Furthermore, because of the seriousness of the issue biological control should be taken seriously. Critical evaluation of known insect enemies and plant-insect interaction should occur, and be selected on a case-by-case basis.

Insect Biocontrol Agents

Insects such as *Brachypterolus pulicarius:* (L.) (Coleoptera: Nitidulidae) are very effective in controlling infestations of *Linaria* spp. *B. pulicarius* affects reproduction allocation, seed production, and dispersal and may reduce the potential for rapid adaptation by dalmatian toadflax because fewer seeds will limit the chance of successful mutations. The ability of *B. pulicarius* to prevent mutations is significant in long-term management strategies, and helps to prevent *Linaria vulgaris* from adapting and out competing reintroduced native species.

Grubb et al., (2001) conducted a study in Montana in 1992 and 1993 on the effects of exotic *B. pulicarius* and how it affects the growth and seed production of *L. genistifolia* (dalmatian toadflax). Grubb's study is relevant because the findings had a similarity to two separate studies Selleck et al. (1957) and Harris (1961) for yellow toadflax. The studies resemble in that *B. pulicarius* adults caused stooling of the yellow toadflax plants by feeding on the young stems. Grubb et al. studied the parasitic relationship in a greenhouse and in field experiments, and evaluated 3 different age groups (3, 6, and 12 months old). Experiments lasted 4 months and were repeated 8 times simultaneously, once in 1992, and a second time in 1993 at the same time of year (early May – early September). Adult beetles generally fed from late May to mid-August (Harris, 1961; McClay, 1992). Adult beetles feed on the new growth at the tips of stems and on the axillary buds at the base of leaves as well as upon the anthers and ovaries within the flowers (Harris 1961; Darwent *et al*., 1975; McClay, 1992).

Results of the study indicated that the effects of *B. pulicarius* on *L. genistifolia* height were dependent on the insect, plant age, and insect *x* plant-age interactions at the time of insect release. Analysis revealed feeding by *B. pulicarius* reduced the height of young dalmatian toadflax plants by up to 23cm; increased the number of primary and secondary branches by 77 and 95%, respectively, and reduced the number of flowers produced per plant by 44 to 49% (Grubb et al. 2001).

Calophasia lunula is useful as a biological agent because it is feeds on the stem and lower leaves of *Linaria vulgaris*. *C. lunula* works well in sites protected from the elements or in areas where a substantial amount of leaf litter exists. It can be useful in a rangeland restoration setting where infested areas transition from open *Artemesia –Purshia* community into aspen stands. Unlike other known insect agents used in biological control, *C. lunula* feeds on all of the major *Linaria* spp., making its food source requirements less strict. *C. lunula* has also made proven its ability to withstand various environmental conditions within a limited range: Since 1989, *C. lunula* has established in Montana, Idaho, Washington, Southern Ontario and Nova Scotia (Rees et al. 1996).

Studies have shown the plant/insect interaction between *Calophasia lunula* and *L.vulgaris.* is positive in relation to weed control. McClay and Hughes (1994) conducted a study to determine the effects of temperature on the distribution, rate and establishment of *C. lunula*, and learned that temperature variability plays a major role in the establishment of the moth. Best survival from larval stage to adult occurred at 24-degrees Celsius. At 18-degrees Celsius its survival was considerably reduced. With a greater understanding of the temperature requirements for the moth, entomologists have identified species of *C. lunula* indigenous to colder regions abroad, and are being evaluated for trial studies in North America where introductions have previously failed.

Etobalea (syn. *Stagmatophora*) spp. (Lep. *Cosmopterigidae),* is another insect that has been used with great success in the control of *Linaria vulgaris.* *Etoblea* is known to hinder *L. vulgaris* through larval mining in the root crown and causes substantial damage to the root system (Rees et al. 1996). *Etobalea* is also known to contribute to the reduced seed weight of *Linaria vulgaris,* however available studies argue whether reduced seed weight actually affects plant survival (Saner and Muller-Scharer 1994).

A study conducted in 1988 by M.A Saner and H. Muller-Scharer experimented with potted plants of *L. vulgaris* to evaluate the effects of root mining by *Eteobalea* spp. Attacked plants had a shorter flowering season and produced seeds of lower weight. Continuous mining during winter resulted in a doubling of the number of stems in spring, but the total plant biomass remained unaffected. Although the absence of treatment-specific mortality in *L. vulgaris* plants does not mean that *Eteobalea* is not effective. A comparison with living plants nearby suggested that the combined effect of drought and high attack rate may kill individual plants. In other investigations it was shown that root herbivory and interspecific competition may affect host plants synergistically (Muller, 1991), hence, the absence of natural competition in the experiments may have resulted in an underestimation of the potential effects of Eeobalea spp.

Mecinus janthus Germar (Col.: Curculionidae), is often recommended for biological control of *Linaria vulgaris*. *M. janthus* is a known stem-borer, effective in controlling infestations of *Linaria vulgaris*. Furthermore, *M. janthus* is recommended because stem-borers are expected to have more impact on *Linaria* spp. than defoliators or seed feeders.

A series of field observations and laboratory screening tests conducted by Jeanneret and Schroder (1988, 1989, and 1990) were compiled into a comprehensive case study to collect information on the distribution, and to investigate the life-history and host specificity of the stem-mining weevil. The impact of the weevil on its host plants was also studied to determine its potential for the biological control of *L.vugaris* and *L.dalmatica*. The studies, which began in 1988 and ended in 1990, have identified that the host range of *M. janthus* is restricted to certain species of the genus *Linaria* and that it develops normally in plants originating from the North America to target populations of yellow toadflax.

Conclusion

The use of biological control as a method of managing weed infestation is realistic in its approach, and in its ability to help managers of rangeland ecosystems toward a state of stability. In cases where infestations are so extensive and dense, success may be judged on the basis of getting to a point where native species can have a competitive advantage against a vigorous weed like yellow toadflax.

As identified by the Integrated Weed Model, some of the most important ways to stop further spread of *L. vulgaris* is preventing it from taking hold in the first place. Often infestations of weeds are not noticed until they have become a major problem. Ideally, the best way to avoid this situation is to prevent weeds from infesting areas that do not have the weed. Preventing weed infestations means educating the community on how to identify yellow toadflax, and instruct them on what to do when they do identify the weed.

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