Keynote Presenter

Integration of biological control into weed management strategies

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Summary

In addition to biological control, many other management techniques including mechanical, cultural and chemical options can be used to control invasive plants. Integration of these strategies with biological control can, in some cases, provide more effective long-term management of a particular weed than the use of a single control option. Herbicides do not generally impact insect populations or pathogens and therefore can be used without compromising the effectiveness of most biological control agents (BCAs). In some cases, particularly with aquatic weeds, the combination of sublethal herbicide concentrations and BCAs can act synergistically. Other studies have used integrated management systems that combine BCAs and prescribed burning. Although burning in spring or summer can kill exposed BCAs, both insects and pathogens are mobile organisms and have the opportunity to readily recolonize the treated site. In other situations, timely burning can increase available nitrogen or remove the soil litter layer, thus benefiting the population growth of BCAs by increasing access to the soil surface or improving the nutrient levels in the target plant. Biological control in concert with competitive, desirable non-target plants can also improve the control of some invasive plant species and prevent subsequent establishment of the weed. Although there are some studies that have demonstrated the benefits of incorporating biological control strategies with other management options, examples of this approach are few. However, with an increased research effort in this area, the potential for successfully using BCAs in an integrated weed management programme is very promising.

Keywords: IPM, invasive plant, biological control, integrated management.

Introduction

The goal of any weed management plan should be not only to control the noxious plant but also improve the degraded community, enhance the utility of that ecosystem, and prevent reinvasion or invasion by other noxious weed species. To accomplish this often requires a long-term integrated management plan. Development of a management programme and selection of the proper tool(s) depends on many factors, including the specific weed species requiring management, its associated vegetative community, initial infestation density, effectiveness of the control techniques, time necessary to achieve control, environmental considerations, chemical use restrictions, topography, climatic conditions and relative cost of the control techniques (DiTomaso et al., 2006c). A number of considerations can influence the choice of options, most important being the primary land-use objective, which can include forage production, preservation of native or endangered plant species, wildlife habitat development, water management and recreational land maintenance. A successful long-term management programme often includes combinations of mechanical, cultural, biological and chemical control techniques (DiTomaso et al., 2006c).

Probably the least studied integrated strategy involves the combination of biological control with other management options. This is due in part to the complexity of such a system compared to other control options, the limited number of weedy species with well-established biological control agents (BCAs) and the interdisciplinary nature of such studies. However, the opportunity to integrate BCAs, whether insects or pathogens, into long-term integrated weed manage-
ment strategies is numerous and have great potential for success.

**Integrated Approaches**

In some cases, a combination of control options may be necessary to facilitate establishment of desirable vegetation or to prevent catastrophic wildfires. For example, in some locations in the western United States, the saltcedar leaf beetle (*Diorhabda elongata* Brullé) has proven to be a very effective defoliator of saltcedar (*Tamarix* spp.). Four to five years of continuous defoliation has begun to result in mortality of saltcedar (Milbrath et al., 2003). Saltcedar in some of these areas can occupy large expanses and the resultant dried vegetative biomass will inevitably increase the fuel load that can potentially lead to large-scale wildfires. As a result, other control options, including prescribed burning and mechanical removal, are being considered as a subsequent option following the success of the insect agent. Although this is an example of an integrated management strategy, saltcedar control is primarily restricted to the use of the BCA. In contrast, most examples of integrated weed management using biological control rely on additional management tools to additively or synergistically contribute to the control of the weed. This review will describe a variety of integrated strategies that have been, or potentially may be, used successfully. Of the integrated approaches combined with biological control, most also involve herbicides, prescribed burning, and/or the use of competitive desirable vegetation.

**Herbicide and biological control agents**

**Terrestrial invasive plants:** Many researchers have evaluated the direct impact of herbicides on weed BCAs (Table 1). In most cases, herbicides do not cause direct damage to insects, and thus can have excellent potential in integrated strategies with biological control organisms.

In some cases, however, herbicides can temporarily disrupt the establishment of a weed biological control programme. In leafy spurge (*Euphorbia esula* L.) stands treated in autumn with 2,4-D and picloram, *Aphthona* spp. were shown to be temporarily less abundant compared to untreated plots, with no significant long-term benefit to weed control (Larson et al., 2007). The authors felt that the flea beetles may have abandoned the herbicide-treated patches for greater resources available in untreated plots. They concluded that there was little advantage to combining herbicides with biological control in areas where biological control is already considered successful.

However, in a yellow starthistle (*Centaurea solstitialis* L.)-infested area in California, the attack rates of the hairy weevil (*Eustenopus villosus* Boheman) and the false peacock fly (*Chaetorellia succincta* Costa) did not differ in the year after a clopyralid treatment (Pitcairn et al., 2000). At this site, the insects did not avoid the treated areas, even though yellow starthistle plant density was considerably lower than the untreated adjacent sites. Lynn and Carlson (1994) noted that the combination of herbicides and biological control was most effective for leafy spurge control if between 15% and 25% of the area was left untreated to sustain insect populations.

One of the key aspects in the proper use of herbicides in combination with BCAs is the timing of the chemical application. Although insect biological control and herbicides represent a very promising integrated management approach for purple loosestrife (*Lythrum salicaria* L.) in North America, applications of the herbicide glyphosate too early in the season can destroy the food source for the leaf beetle *Galerucella calamiensis* L. (Lindgren et al., 1999). This is of particular concern where the beetles are well established. A late-season application of the herbicide, when plants are in bloom, is more compatible with *G. calamiensis*.

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Table 1. List of biological control insects, target weed species and herbicides that can be applied without damage to the insect.

<table>
<thead>
<tr>
<th>Insect biocontrol agent</th>
<th>Target weed species</th>
<th>Herbicide</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Rhinoclylus conicus</em> Froehlich</td>
<td><em>Cardus</em> spp.</td>
<td>2,4-D</td>
<td>Trumble and Kok, 1980</td>
</tr>
<tr>
<td><em>Cethorhynchidius horridus</em> Panzer</td>
<td><em>Cardus</em> spp.</td>
<td>2,4-D</td>
<td>Trumble and Kok, 1980</td>
</tr>
<tr>
<td><em>Sphenoptera jugoslavica</em> Obenberger</td>
<td><em>Centaurea diffusa</em> Lam.</td>
<td>Picloram, Clopyralid</td>
<td>Wilson et al., 2004</td>
</tr>
<tr>
<td><em>Cyphocleonus achates</em> Fahrreus</td>
<td><em>Centaurea maculosa</em> Lam.</td>
<td>Picloram</td>
<td>Jacobs et al., 2000</td>
</tr>
<tr>
<td><em>Urophora affinis</em> Frld. and <em>U. quadrifasciata</em> Meig.</td>
<td><em>Centaurea maculosa</em></td>
<td>2,4-D, Picloram</td>
<td>McCaffrey and Callihan, 1988; Story et al., 1988</td>
</tr>
<tr>
<td><em>Eustenopus villosus</em> Boheman and <em>Chaetorellia succincta</em> Costa</td>
<td><em>Centaurea solstitialis</em> L.</td>
<td>Clopyralid</td>
<td>DiTomaso et al. 2006</td>
</tr>
<tr>
<td><em>Hyles euphorbiae</em> L.</td>
<td><em>Euphorbia esula</em> L.</td>
<td>2,4-D, Picloram</td>
<td>Rees and Fay, 1989</td>
</tr>
<tr>
<td><em>Spurgia esulae</em> Gagne</td>
<td><em>Euphorbia esula</em></td>
<td>2,4-D, Picloram</td>
<td>Lym and Carlson, 1994</td>
</tr>
<tr>
<td><em>Galerucella calamiensis</em> L.</td>
<td><em>Lythrum salicaria</em> L.</td>
<td>Glyphosate, Triclopyr</td>
<td>Lindgren et al., 1999</td>
</tr>
</tbody>
</table>
than an early season application because most adults will have already entered winter diapause. In this situation, *G. calmaris* would potentially control young purple loosestrife seedlings in the following season (Lindgren et al., 1999).

Autumn applications of 2,4-D and clopyralid were not compatible with two competing insects, *Cephaloleius achates* Fahraeus and *Agapetae zeogena* L., for the control of spotted knapweed (*Centaurea maculosa* Lam.), whereas spring treatments were compatible (Story and Stougaard, 2006). This was due to the low level of survival of the larvae following autumn application timing. By comparison, spring application of 2,4-D plus picloram for leafy spurge control was detrimental to *Aphthona* spp. establishment, as it eliminated the adult food source. However, autumn applications did not negatively affect establishment or reproduction of the flea beetles, and when used in combination, leafy spurge control was better and more economical than either method used alone (Lym et al., 1996; Lym, 1998; Lym and Nelson, 2002). In the year after the herbicide treatment, leafy spurge stem density decreased by 85% to 95% when applications were made to plants infested with the BCAs (Lym et al., 1996; Lym and Nelson, 2002). In contrast, when only the insects were present, it took 3 years longer to reduce the infestation to the same level achieved in 1 year with the integrated strategy. Once leafy spurge density was reduced, the *Aphthona* flea beetles maintained acceptable control for at least an additional 7 years (Lym and Nelson, 2002). This resulted in a threefold to fivefold cost savings to land managers who typically reapPLY herbicides annually for a number of years. Lym (1998) concluded that the benefit of this combination was due to the decrease in seed production through the activity of the insects and the inhibition in vegetative spread by creeping roots through the action of the herbicide. The response was even better when *Aphthona* spp. populations were already established at the time of the herbicide treatment (Lym and Nelson, 2002).

Another study integrated the root-feeding beetle *Sphenoptera jugoslovica* Obenberger with low rates of picloram or clopyralid for the control of diffuse knapweed (*Centaurea diffusa* Lam.). The results indicated that, compared to other months, a June herbicide application in Colorado (USA) was the most compatible with the insect and improved control compared to either technique used alone (Wilson et al., 2004). The June treatment timing mimicked a midsummer arrest of diffuse knapweed growth that is normally triggered by late-summer drought. Insect damage is greater in drought-stressed plants than in other periods of the season when plants have adequate moisture. Herbicides applied in June increased infestation of diffuse knapweed plants by the root feeder by 25% the year after treatment compared to untreated areas. This response was suggested to be due to the herbicide-induced arrest in summer growth (Wilson et al., 2004).

Pitcairn et al. (2000) hypothesized that combining clopyralid application with insect BCAs could provide more effective long-term control of yellow starthistle. While an initial clopyralid application would reduce plant density and new recruitment into the seed bank, subsequent activity of the BCA on seed production would slow the rate of reinfestation. In a field study to test this hypothesis, they found that 1 year following a clopyralid treatment, there were no significant differences in attack rates between the treated and untreated populations, despite the low density of yellow starthistle in the treated area (Pitcairn et al., 2000). In the year after treatment, they also found that BCAs suppressed seed production by 76% compared to controls. If successful, the combination of the two control methods would reduce the need for continuous herbicide treatments.

**Aquatic invasive plants:** A number of studies have also demonstrated the value or potential value of using biological control in an integrated approach with herbicides in aquatic systems. For example, the efficacy of two biological control weevils, *Neochetina eichhorniae* Warner and *N. bruchi* Hustache, was compared for control of water hyacinth, *Eichhornia crassipes* (Mart.) Solms, in both a managed aquatic system, where the herbicide 2,4-D was routinely applied as a maintenance treatment, and an unmanaged site with no herbicide treatment. The maintenance treatment did not eliminate water hyacinth. Rather, it resulted in lower insect populations and fewer but healthier, more vigorous plants with higher nutritional quality (Center et al., 1999). Despite the lower insect populations over time, the weevils benefitted from the herbicide treatment compared to the untreated area. Intraspecific competition in the unmanaged site led to smaller, more stressed individual plants that were less suitable for weevil populations. The larger plants of the managed areas enhanced weevil reproduction and, in the long-term, provided more sustainable control of water hyacinth. The authors concluded that such an integrated approach can exploit the benefits of both methods while minimizing the negative aspects of each (Center et al., 1999).

Combinations of sublethal herbicide rates and pathogens have been used synergistically to increase the susceptibility of the target species, while reducing the damage to non-target plants. This approach has been used for the control of Eurasian watermilfoil *Myriophyllum spicatum* L. (Sorsa et al., 1988), coontail *Ceratophyllum demersum* L. (Smit et al., 1990) and particularly for hydrilla *Hydrilla verticillata* (L.f.) Royle (Netherland and Shearer, 1996; Nelson et al., 1998; Shearer and Nelson, 2002).

Applying a sublethal concentration of either fluridone or endothall in combination with a hydrilla-specific fungal pathogen, *Mycoleptodiscus terrestrial* (Gerd.) Ostazeski, reduced hydrilla biomass by >90% and was considerably more effective than using the herbicide or pathogen alone (Netherland and Shearer, 1996; Nelson et al., 1998; Shearer and Nelson, 2002). It was hypoth-
esized that the sublethal rate of either herbicide stressed the hydrilla plants by inhibiting growth and weakened their natural plant defense system, thus increasing their susceptibility to pathogen attack (Netherland and Shearer, 1996; Nelson et al., 1998). For fluridone, the combination also reduced exposure time. Using either endothall or fluridone alone required higher rates that also caused injury to desirable native aquatic plants, including vallisneria (Vallisneria americana Michx.) and native pondweeds (Potamogeton spp.) (Nelson et al., 1998; Shearer and Nelson, 2002). By using a lower rate of the herbicide with the pathogen, excellent selectivity was achieved and the damage to these non-target species was minimal.

Prescribed burning and biological control agents

In many areas, prescription burning can be used to reduce the incidence of catastrophic wildfires (Briese, 1996) or to control invasive plants (DiTomaso et al., 2006a,b,c). When used in combination with biological control, the timing of prescribed burning needs to take into consideration the reproductive capacity and life history of the BCAs. As with the combination of herbicides and biological control, some unburned patches should be preserved to maintain a refuge population of the BCAs (Briese, 1996).

For the integrated control of leafy spurge using burning, Fellows and Newton (1999) showed that burning conducted between mid-May and October did not have a detrimental effect on larval survival in Aphthona nigriscutis Foudras and increased the insect’s establishment by more than twofold compared to unburned areas. During this timing interval, the adults were not active and the juveniles were below ground. The enhanced establishment of A. nigriscutis was due to an increase in colonization in the bare ground created by the burn. It was postulated that the litter layer interferes with reproduction of the BCAs. A. nigriscutis is considered difficult to establish in dense, mixed stands of leafy spurge and grass. Burning, however, increased the initial density of leafy spurge in the first growing season after the burn, which increased colonization through recruitment. However, the increase in insect populations gave about seven times better control than in the unburned site by the end of the first year (Fellows and Newton, 1999). Based on these results, the authors concluded that periodic burning of leafy spurge patches at the proper time of year would lead to expansion of the established colonies and provide earlier control of leafy spurge (Fellows and Newton, 1999).

A similar situation was also reported for common St. Johnswort (Hypericum perforatum L.). Prescription burning stimulated an increase in the crown density of the species through vegetative regrowth from rootstocks and lateral roots (Briese, 1996). Concomitant with this, St. Johnswort beetle (Chrysolina quadrigemina Suffrian) populations dramatically declined as a result of the fire. Interestingly, insect numbers quickly rebounded, primarily through influx of the beetle from adjacent non-burned sites. This increase in the beetle population in the burned site was associated with increased recruitment and fecundity due to higher available nitrogen and perhaps other nutrients that stimulated plant growth in the burn site. High foliar nitrogen levels in these St. Johnswort plants were associated with a population buildup of the beetle, which may have recognized the burn sites as favourable feeding areas (Briese, 1996).

Prescribed burning has been shown to be an effective tool for the management of yellow starthistle in California (DiTomaso et al., 2006b). At the same time, several biological control insects are widespread throughout the state and there is some concern that prescribed burning may negatively impact the presence or activity of these organisms. A study conducted by DiTomaso et al. (2006b) showed no significant reduction in the attack rates of false peacock fly (C. succinea) in a burn site 1 year later. For hairy weevil (E. villosus), attack rates were high in both burned and adjacent unburned areas but were highest in the burned areas. Thus, despite the likely death of weevil larvae within the seed heads of yellow starthistle in the burned site the previous year, new recruitment of BCAs the following year was rapid.

Plant competition and biological control agents

The competitive ability of a plant can be significantly compromised by the activity of biological control organisms. Insects that bore into roots, shoots and stems, defoliate the plant, destroy seeds or extract plant fluids can reduce the competitive ability of that plant with regard to its neighbouring vegetation (DiTomaso et al., 2006c). Similarly, pathogens that infect the vegetation or underground parts can reduce the photosynthetic ability, water-mining capacity or vegetative growth of a species. The density and cover of spotted knapweed in the western United States is generally lower in areas with higher grass competition (Müller-Schärer, 1991). Story et al. (2000) released the root-mining moth A. zoegana into two adjacent areas, one with high grass cover (~50%) and the other with low grass cover (~10%). After monitoring the buildup of moth populations, as well as the effect on the number of bolting spotted knapweed plants, they found that by the third year, the percentage of knapweed plants infested with A. zoegana in the high grass-cover plots was nearly twice that of the low grass-cover plots. This corresponded to a 50%
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reduction in the number of bolted plants per unit area in the high-grass site compared to the low-grass site.

Conclusion

Although there are few studies focused on combining biological control efforts with other weed management techniques, there are great opportunities to increase the efficiency of weed management strategies using integrated combinations. The potential exists for BCAs that may currently be considered ineffective when used alone to be successful when combined with other control techniques. The complexity of these systems, however, requires a comprehensive understanding of the biology and ecology of the organisms, appropriate timing of the treatments and the long-term effects. Over time, integrated management approaches may provide more effective and economical options compared to the use of single management techniques.

References


