Are mono-specific agents necessarily safe?
The need for pre-release assessment of probable impact of candidate biocontrol agents, with some examples

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Summary
Historically, weed biocontrol practitioners searched for highly effective agents that were also safe. Protecting agronomic crops was the original focus for risk evaluation, but to this has been added protecting native plants, especially those related to the target weed. Host range tests are now weed biocontrol’s hallmark tool, with concern about the efficacy of the candidate agent sometimes being secondary. However, even a highly specific agent can disrupt ecosystem pathways in unpredictable ways, especially if it becomes abundant on its target, but fails to reduce the target weed’s populations. I review some of the current concerns about non-target impacts, both direct and indirect, as well as criticisms about the inefficient “lottery” approach that wastes scarce resources in introducing many agents, some of which never contribute to controlling the target weed. Effective agents can help alleviate some of these concerns, and there is increasing demand that we should strive to release agents that are not only narrowly host specific, but also have demonstrated their ability to damage the target weed. While still not yet routine, pre-release consideration of the proposed agent’s probable efficacy is receiving increased attention. This is usually done overseas, in the native range of both the target weed and candidate agent. I review some of the different approaches used in these overseas evaluations. However, pre-release impact assessments can also be performed under containment conditions in quarantine. I discuss the results of two “dosage” trials I conducted with a gall-making fly that is being considered as a biological control agent for Cape ivy (Delairea odorata). Plants exposed to both low and high densities of gall flies, were smaller, and had fewer leaves than the ungalled controls. Pre-release evaluations of a candidate agent’s potential impact should lead to fewer ineffective agents being released, thereby making weed biocontrol more efficient, and reducing [but not eliminating] the possibility of negative indirect impacts on non-targets.

Keywords: efficacy, indirect impacts, ineffective agents, non-target impacts, risk reduction.

Introduction
Within the subdiscipline of biological control of weeds, those involved in selecting potential agents have always been concerned that the agent would contribute to the eventual control of the target weed. Early numerical scoring systems for prioritizing potential weed biocontrol agents were heavily weighted towards an agent with demonstrated impact (Harris 1973, Goeden 1983). In the early decades of weed biocontrol, concern for non-target effects concentrated on possible impacts to crops and other agronomic plants. However, by the early 1970s this concern began to shift to native plants (Pemberton 2003). The host specificity of potential weed biocontrol agents became of paramount importance, and test plant lists became quite lengthy, with concern about the efficacy of the candidate agent sometimes being secondary. Despite this emphasis on host specificity, biological control of weeds continues to draw criticism, both from practitioners and outside observers. The most troubling criticisms can be lumped into two categories: 1) non-target impacts and 2) inefficiency.

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Direct non-target impacts

Non-target impacts caused by biological control agents appears to be a current “hot topic”, with two recent books (Follett & Duan 2000, Wajnberg et al. 2001) and a review article (Louda et al. 2003) being devoted primarily to this subject. The impacts resulting after the release of an agent can be classified as either direct or indirect (usage follows Fowler et al. (2001) and Lonsdale et al. (2001)). The former results from direct action (feeding, galling, oviposition) by the agent on a target or non-target. Indirect impacts include those resulting from the decrease of the target weed or the agent becoming a food source or disease vector, and can affect species that do not even directly encounter the biological control agent. As pointed out by Lonsdale et al. (2001), both forms of impacts are desired end products for a successful weed biocontrol project. For example, the agent should directly reduce the abundance of the target weed, and this reduction should indirectly allow for replacement by native plants, crops or forage plants. But an agent can also cause undesirable, negative impacts on non-targets, both directly and indirectly. These are among the outcomes of biological control to which McEvoy & Coombs (2000) apply Tenner’s (1996) term “revenge effects”.

Due primarily to the long-standing concern by weed biocontrol scientists about the host specificity of the agents that they release, our subdiscipline has an enviable record of safety with very few instances of direct impacts on non-targets (McFadyen 1998). For example, although more than 350 organisms have been released to control 130 weed species world-wide, only eight examples of impacts on non-target plants are known and most of these were predictable from the pre-release tests (Julien & Griffiths 1998). In a more recent review by Pemberton (2000) of the data on field host use by the 117 biological control agents released against weeds in the continental USA, Hawaii, and the Caribbean since 1902, he found that 15 insect agents also utilize 41 native plant species. All but one of these plants are closely related to the target weed, and the potential for attack by the agents could have been predicted from host-specificity testing. Though Stiling & Simberloff (2000) might argue otherwise, unpredicted non-target impacts from weed biological control agents appear to be relatively uncommon.

It should be remembered that, although direct impacts to a native plant are undesirable, the mere possibility of this occurring does not necessarily disqualify a potential agent from being released, even under the current more stringent regulatory environment. Adequate host range testing, coupled with good information on the distribution and ecology of both the weed and the potential non-target host can allow for reasonable predictions of severity of non-target attack as well as a risk–benefit analysis. For example, Willis et al. (2003) review nine weed biocontrol projects in Australia that included a proposed agent whose pre-release host range evaluations indicated a risk to a native Australian plant. In all nine cases, the agents were ultimately approved and released.

Indirect non-target impacts

Direct impacts to non-targets are usually predictable from host-specificity evaluations. Host range data can also provide guidance about the most plausible kind of indirect impacts – those arising from the “knock-on” (Fowler et al. 2001) or “downstream” effects from the [hoped for] decrease in the population of the target weed [or other host]. If, for example, the weed now serves as food or shelter for a native species, a conflict of interest might exist. The biological control of Tamarix spp. (salt cedar) in the western United States was delayed for many years because of concerns for the western willow flycatcher, a threatened bird subspecies that had started to nest in this invasive shrub (Stenquist 2000). Stiling & Simberloff (2000) also cite as an example Hayes et al. (1995) concerns that Cactoblastis moths are destroying the prickly pear on a Bahaman islet, where it is the major food source for the San Salvador rock iguana.

Similar “downstream” indirect impacts might be expected if the agent also has other hosts. This is the case for the now notorious Rhinocyllus conicus weevil whose attack on native North American thistles is also displacing some of the native insects that feed on them (Louda et al. 1997, Louda 2000). There does, however, now seem to be a consensus that the damage to native thistles by this weevil was predictable from the pre-release and early post-release evaluations (Gassmann & Louda 2001).

Host range evaluations are of little use, however, in predicting other indirect impacts that might arise from any of the myriad possible disruptions that a weed biocontrol agent might cause to complex food webs. While such food-web disruptions have been theorized as possible for weed biocontrol agents (Simberloff 1991, Simberloff & Stiling 1996), there have been few documented cases of negative indirect impacts to food webs. We do, however, know that new tritrophic relationships arise after release of biocontrol organisms, including those used for weeds. Many weed biocontrol insects soon acquire native parasitoids that find them acceptable hosts (McFadyen 2003). An example is the native wasp, which now parasitizes up to 30% of the pupa of the Hydrellia spp. flies that were introduced in the USA to control the aquatic weed Hydrellia verticillata, and which is suspected of reducing the effectiveness of these agents (Balciunas et al. 2002, Grodowitz 2003). The populations of this wasp are now undoubtedly higher, but the impact of these higher parasitoid populations on their original native Hydrellia hosts is unknown.
Although not accepted by everyone, perhaps the most convincing evidence of food-web disruption by a weed biocontrol agent is the recent research into predation by native deer mice on the larvae of the *Urophora* spp. gall flies released to control spotted knapweed. Released in Montana nearly 30 years ago, these gall flies have not been found attacking any native plants, and they are now ubiquitous and very abundant, but they have failed to arrest the spread of the knapweed, and their larvae are now the preferred prey for native deer mice, whose populations appear to have increased as a result (Pearson 1999, Pearson *et al.* 2000). Since these mice are the primary vectors of hantavirus, the incidence of this serious disease in humans may increase (Stiling & Simberloff 2000). While the more dire of the possible ecosystem perturbations flowing on from the abundance of these gall flies may not be confirmed, I, for one, accept that weed biocontrol agents can and do modify food webs.

### Inefficiency of the lottery approach

One result of the current emphasis on host-specificity of weed biocontrol agents is that many of the most damaging potential agents are rejected for consideration for release because they also damage other plant species. Frequently, agents causing less damage are selected for release, and often many different agents are released against the same weed target in the hope that one or several, acting cumulatively, might provide adequate control. This approach, termed the “lottery model” by Myers (1985) does not appear to have clear-cut superiority in providing control, and it does have drawbacks. McEvoy & Coombs (1999, 2000) criticize the lottery model as being inefficient, lacking enough post-release monitoring, and being prone to “revenge effects”. They urge a more “parsimonious” approach, and this recommendation is echoed by other reviewers (e.g. Strong & Pemberton 2001, Sheppard 2003).

### Testing candidate agents for potential impact

I agree with those who believe indirect impacts, such as those that *Urophora* flies are having on deer mice, cannot readily be predicted before release. However, I believe that, with additional testing beyond the traditional host-specificity tests, the probability of such indirect impacts can be reduced. Intuition indicates that non-target impacts from a biological control agent are most likely to occur if the agent becomes very abundant. While biocontrol specialists hope that, after release, the agent will establish and become abundant, these high populations of the agent should be followed by the collapse of the populations of the target pest, and subsequent decline of the agent. Likewise, Holt & Hochberg (2001, p.31) conclude from their theoretical studies of a “shared predation” model that “a control agent which is only moderately effective at limiting target species numbers may be much more abundant than an effective agent, and thus pose a greater risk of incidental attack”. Ecological models (Lynch *et al.* 2001, Kriticos 2003) and construction of quantitative food webs (Memmott 2000) can assist in delineating some of these non-target risks. But the prudent approach will be to demonstrate, before release, that a candidate agent has the potential to reduce populations of the target weed. Agents causing lethal damage to the target weed may not need to undergo this additional testing for impact. Pre-release demonstration of potential efficacy of agents should allow for selection of more effective agents. This should not only reduce the likelihood of indirect non-target impacts and other “revenge” effects, but will counter other objections to the “lottery” approach, as well as making weed biocontrol more “parsimonious”.

### Table 1.

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<td>1.</td>
<td>Ensure target weed’s potential impact justifies release of non-endemic agents</td>
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<td>2.</td>
<td>Obtain multi-agency approval for target</td>
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<td>3.</td>
<td>Select agents with potential to control target</td>
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<td>4.</td>
<td>Release safe and approved agents</td>
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<td>5.</td>
<td>Ensure only the intended agent is released</td>
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<td>6.</td>
<td>Use appropriate protocols for release and documentation</td>
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<td>7.</td>
<td>Monitor impact on target</td>
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<td>8.</td>
<td>Stop releases on ineffective agents, or when control is achieved</td>
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<td>9.</td>
<td>Monitor impacts on potential non-targets</td>
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<td>10.</td>
<td>Encourage assessment of changes in plant and animal communities</td>
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<td>11.</td>
<td>Communicate results to the public</td>
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Within the subdiscipline of classical biological control of weeds, the need for selecting effective agents is receiving new emphasis, and pre-release assessment of a candidate’s potential impact is often urged (Harris 1991, Cullen 1995, McEvoy & Coombs 2000, Hopper 2001, Strong & Pemberton 2001, Sheppard 2003). Likewise, the “International Code of Best Practices for Classical Biological Control of Weeds” (Table 1) urges practitioners to select effective agents and, after release, to monitor them for both beneficial and non-target impacts (Balciunas 2000). As a result, pre-release evaluations of impact are becoming more common. These pre-release assessments of a potential agent’s efficacy are usually performed in the native range of both the target and agent, under non-containment conditions. They can take several forms. Overseas surveys of natural enemies
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can be quantified, thereby providing relative abundances and field attack rates that can greatly aid in agent prioritization (Balciunas et al. 1995a, 1995b, Sheppard et al. 1994, 1995, Briese 2000). One type of pre-release assessment that can be performed only in the native range is “Exclusion Studies” where the target weed is protected from attack by potential agents. For example, an 11-year insecticidal exclusion study in Britain demonstrated that broom bushes protected from insect herbivores outgrew those that did not (Waloff & Richards 1977). In a more recent study in Australia, the home of Melaleuca quinquenervia (Cav.) Blake, Balciunas & Burrows (1993) used insecticides to exclude insects from attacking the “control” saplings of melaleuca, and demonstrated that sprayed saplings quickly outgrew those that were unprotected (Fig. 1), and were able to infer that two insect species were likely responsible for this suppression of sapling growth. The impact of potential agents can also be assessed in the native range through experimental manipulations of their density under field conditions (Hasan & Aracil 1991 Brun et al. 1995) or in cages (Briese 1996).

While assessments of potential agents’ probable efficacy are increasingly being performed in their native range, they are seldom done under the more constrained conditions a quarantine facility. Recently, I demonstrated that assessment of probable impact of a potential agent is possible under the strict containment conditions of an approved quarantine facility. I conducted two trials exposing test Delairea odorata (Cape ivy) plants to two different densities of Parafreutreta regalis gall-forming flies, and, after approximately two months, comparing the growth of the galled vines to similar vines that had not been exposed to flies. Under both the high density (10 pairs of flies/plant) (Fig. 2) and low density (2 pairs/plant) treatments, the galled vines exhibited visible stunting, and the non-galled plants were statistically longer, and had more nodes and larger leaves. These trials confirmed that relatively subtle, sublethal impacts on the target can be quantified, even under strict containment conditions, and this should encourage others to more routinely, prior to release, to assess the potential impact of prospective agents on their proposed target.

In conclusion, the renewed interest in a candidate agent’s efficacy is leading to more pre-release evaluations of their potential impact. This should lead to the release of fewer ineffective agents, making weed biocidal more effective and less susceptible to “revenge effects”, including indirect impacts on non-targets.

**Figure 1.** Comparison of the mean height of 20 pairs of potted Melaleuca quinquenervia saplings growing in Townsville, Australia. One sapling from each pair was sprayed with a systemic insecticide every two weeks, while the other (the control) was left untreated. After just 84 days, the difference in height had become statistically different (Student’s T-test, P < 0.05) (from Balciunas & Burrows 1993).

**Figure 2.** Comparison of the mean measurements, after two months, for the four control Delairea odorata (Cape ivy) plants, with the means for the six Cape ivy plants that were continuously exposed to 10 pairs of Parafreutreta regalis gall-forming flies. The asterisk * above the columns indicates that the means were significantly different (Student’s T-test, P < 0.05) (Balciunas, unpublished data).
References


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