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The Double-Edged Sword of Biological Control in Conservation and Restoration

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Introduction

The most fundamental question in considering deliberate introductions of exotic species against invasive species is whether the outcomes can be predicted precisely enough a priori to know with some certainty that the benefits will outweigh the environmental costs. This issue is obscured by reiteration of an overly simplistic description of the ecology underlying biological control. Classical biological control is not a simple exercise in "community re-assemblage" (Hoddle 2004[this issue]); it involves the introduction of alien organisms into new species assemblages, in new physical environments, and without the rest of their foodweb. Predicting the outcome of such introductions is infinitely more complex than implied by the idea of "reestablishing natural enemies" of an invasive species. Direct ecological interactions are difficult enough to predict, but indirect interactions—those mediated through a third species or foodwebs—are even harder to predict (Strauss 1991; Paine 1992; Wooton 1994; Menge 1997). In suggesting that biocontrol efforts are "restoring balance" by "using exotic species to control invasive exotic species,"Hoddle (2004 [this issue]) skirts the essential ecological issue: predicting the magnitude of the outcome of the full set of new interactions in a new environment.

Our aim is to review more, highly relevant evidence and to outline an alternative, ecological perspective on the use of "exotics to control invasive exotics" (Hoddle 2004). We summarize data on nontarget effects that were ignored or that challenge Hoddle's interpretations and then briefly address the points he raised on classical biological control. This synopsis highlights important reasons for increased caution and continuing development of improved ecological risk assessment, especially for conservation and restoration. In these contexts in particular, we think that the overarching guideline, as in medicine, should be, first, do no harm (Simberloff & Stiling 1996).

More Evidence on Nontarget Effects

Recent quantitative studies show unexpected levels of nontarget feeding and impact by some biological control insects (Howarth 1991; Follett & Duan 2000; Wajnberg et al. 2001). Several studies not cited, or dismissed, by Hoddle provide additional strong, quantitative evidence that biological control efforts can have more far reaching and complicated outcomes than expected. To predict the interaction outcomes observed, adequate risk assessment prior to release would have required more ecological data to supplement the behavioral and physiological data from host-specificity tests (Louda 1999; Louda et al. 2003a; 2003b).

Johnson and Stiling (1996) reported significant feeding by the moth *Cactoblastis cactorum* on native cacti in southern Florida, which is within hitch-hiking or island-hopping distance of the Caribbean islands onto which the moth was introduced as a biocontrol agent (Stiling 2002). In Florida the moth now threatens the already endangered native *O. corallicola* with extinction (Stiling et al. 2000). This moth is a specialist on the genus *Opuntia*, so the case highlights the fact that narrow host specificity per se does not guarantee safety (Louda et al. 2003b). The case also suggests the need to expand quantitative assessments of potential ecological risks to adjacent regions within potential dispersal distance.

Louda and colleagues (1997; 1998) reported that *Rhinocyllus conicus*, a thistle specialist introduced to control exotic species, is both widespread and reducing seed production by multiple native thistles in nature reserves and three national parks in the central United States. Prior data (Louda & Potvin 1995) make it clear that the

further decreases in seed production threaten populations of *Cirsium canescens* in its habitat, one without the targeted exotic thistle (Louda 1999). The weevil also interferes with native floral insects dependent on native thistles (Louda & Arnett 2000). This weevil is a specialist on thistles, so this case highlights the fact that a "narrowly specific host range" is relative to the species composition of the recipient region. The case also suggests the need to add insect population response under various conditions in assessments of ecological risk (Louda et al. 2003a; 2003b).

Callaway and colleagues (1999) reported that feeding by two specialized tephritid flies (*Urophora affinis, U. quadrifaciata*) introduced against exotic knapweeds (*Centaurea maculosa*, *C. diffusa*) indirectly facilitates knapweed growth. Furthermore, Pearson and colleagues (2000) found that when the flies failed to control knapweed, the abundant fly larvae subsidized populations of deer mice (*Peromyscus maniculatus*), a generalist predator, and mouse populations increased two- to three-fold. As a result, other small mammals have declined, and the native plant community has been altered. This case highlights the need for evidence of a high probability of control, prior to release of putative biocontrol agents. It also illustrates the complexity of outcomes possible with the insertion of exotic species into new communities. Evaluation of such outcomes is not a part of contemporary ecological risk assessment.

Henneman and Memmott (2001) found that insects released as biological control agents in agroecosystems at low elevations on Kauai, Hawaii, have penetrated the high-elevation native forest to the point that an unexpected 83% of the parasitoids reared from native caterpillars are biocontrol agents. This case highlights the probability of dispersal away from the targeted areas into adjacent natural communities. It also illustrates the potential consequences for the community foodweb of introduced exotic species.

Louda and O'Brien (2002) reported large nontarget effects of *Larinus planus* on the sparse native *Cirsium undulatum* var. *tracyi* in Colorado. This Eurasian weevil was tested in Europe, first observed as an adventive in a biological control test field in the northeastern United States (White 1972), and released officially in Colorado as a biocontrol agent against *C. arvense* (Canada thistle). Release in Colorado occurred even after contemporary host-specificity tests showed that native species were acceptable, but not preferred, hosts (McClay 1990). Unfortunately, however, seed destruction by *L. planus* is greater on the native species than on the targeted weed. This case illustrates three key points: a discrepancy between predicted host use, based on host-preference tests, and observed host use in the field; the dangers of redistribution of potential "natural enemies" between ecosystems; and shortcomings in the oversight process for movement of "beneficial" exotic species within the country.

In sum, these data augment the cases listed by Hoddle (2004) and document both unexpected interactions and unpredicted intensities of interaction with native species by insects used as biological control agents. Much of the recent evidence emerged serendipitously in the midst of basic ecological studies. Thus, given the general lack of follow-up monitoring in biological control and the serendipity of much of the quantitative data on nontarget effects, the evidence now available may represent only the tip of the iceberg. The current state of knowledge argues for more studies and increased caution in deliberate introductions of exotic species.

Reasons for Caution and Better Development of Risk Assessment

The issue is not whether biological control is an option in invasive species management. Given the evidence on the unexpected range and magnitude of nontarget effects, the real question is when biocontrol is likely to be both effective and environmentally safe. Long-standing arguments underlying advocacy of classical biological control efforts, reiterated by Hoddle, are (1) economic and environmental benefits, (2) rarity of nontarget effects by specialist insects, (3) regulatory "safety net," and (4) value to conservation. Each of these points has counterpoints that merit repetition, to increase awareness of the questions underlying the assertions and to stimulate further science-based dialogue to resolve the real issues.

First, we concur that biocontrol can be beneficial, *when it works.* The key phrase, however, is when it works. The probability of control, and thus the likelihood of benefit, is not evaluated quantitatively in pre-release studies. Yet ineffective releases do nothing about the pest and have multiple ecological risks. Hoddle claims that "science-based biological control programs are deliberate and carefully orchestrated … ." Usually, however, as many relatively specific biocontrol agents as can be identified are released in hopes that one will limit the targeted pest, without assessment of the likely outcome or even probability of unwanted interactions among agents (McEvoy & Coombs 1999, 2000). Moreover, the statistics on success are not encouraging. Based on quantitative criteria, only 20% of weed-control projects (Williamson & Fitter 1996) and 3% of insect-control projects (Lynch & Thomas 2000) exhibit successful control. Lack of control not only entails unnecessary costs, it can lead to new problems (e.g., Pearson et al. 2000). It also leaves the 34–50% of the exotic insects that become established in the new environment, without controlling their targeted pest (Greathead & Greathead 1992). More precise economic analyses, and more accurate representations of the likelihood of success are needed to put the potential ecological costs into a more realistic perspective.

Second, although use of specialist insects reduces the chance of direct nontarget use (Pemberton 2000), it is not foolproof (Louda et al. 2003b). Hoddle argues that "Natural enemies that exhibit high levels of host and habitat fidelity ensure strong links and maximal impact on the target species, while ensuring weak links and minimal impacts to nontarget species." The problem, of course, is defining "high" in this context. The cases above, and others (Louda et al. 2003b), show that nontarget effects can be imposed by relative "specialists," species whose diet is limited to a set of closely related hosts. Furthermore, most insects released against insect pests do not narrowly specialize; 62% of parasitoids released are polyphagous (Stiling 1990). At least 23.6% of the 313 parasitoids released against insect pests in the United States attack nontarget species (Hawkins & Marino 1997). Also, despite claims to the contrary (Hoddle), host-range expansion by specialized natural enemies occurs: at least 20 cases have been identified (Secord & Kareiva 1996). Further, nontarget effects are not as rare as suggested; direct, indirect, and cascading effects have been reported (above). Together, these results undermine confidence in relative specialization and host preference as completely adequate criteria for estimation of ecological risks.

Third, although the strict regulatory oversight legislation enacted by New Zealand and Australia provide models for other countries, this safety net is not universal. Voluntary codes are just that, voluntary. Regulators are under political pressure to minimize oversight and are under financial constraints that have a comparable effect. Expediency can overwhelm good intention. Finally, once an exotic species is established, few if any countries have comprehensive, science-based guidelines for internal movement of "beneficial" insect enemies between regions and ecosystems. In sum, we are not persuaded that voluntary restraints and current regulatory oversight protect sensitive natural resources of conservation value in most countries.

Fourth, evidence now suggests that biocontrol may not be as risk-free an option for conservation and restoration as is assumed. We still do not know enough to predict the ecological outcomes of new biological interactions, including deliberate introduction of exotic species. Evaluation procedures in biological control, which rely heavily on host-specificity tests, are not designed to quantitatively predict population impacts on either targeted or nontargeted species or to quantitatively predict alternative outcomes in complex assemblages of species. Why is this important? The magnitude of potential benefits and costs are not well quantified prior to introduction, so trade-off analyses are much more hypothetical than generally thought. This realization is crucial in conservation contexts, where the overarching mandate is to protect native species. Increasing caution, ever-increasing scientific rigor, and a careful reexamination of the assumptions underlying current protocols are needed to improve the prediction of ecological dynamics and outcomes among newly associated species in new environments. Advising increased caution in the application of biocontrol is not to advocate a do-nothing policy. Mechanical and localized chemical control methods exist and, although they take time and resources, may represent less harmful containment strategies in the long run than introducing self-replicating, self-dispersing, irretrievable biological "natural enemies" with unexpected ecological side effects.

Conclusion

Biological control is a potential tool in the fight to control invasive exotic species, but it is clearly a double-edged sword. Given the evidence available, we think the focus now should be on when biocontrol will be both effective and ecologically safe. Although Hoddle acknowledges some of the problems, his basic message could be construed as a generalized recommendation for biocontrol in sensitive natural areas. Yet it is important to avoid using classical biocontrol as the reflexive response to invasive species (Michaud 2002). The evidence now contradicts the simplistic, optimistic perspective that the practice of introducing and redistributing exotic species is so carefully targeted, so adequately analyzed, and so well regulated that—done according to current protocols—it poses no credible ecological risk to natural systems. We disagree and conclude that better quantification of both likely benefits and possible ecological costs are required before applying the dramatic and potentially risky strategy of introducing exotic spcies against exotic species in a conservation context.

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