The Garlic Mustard (*Alliaria petiolata*) Case,
What Makes a Good Biological Control Target:
The Intersection of Science, Perspectives, Policy and Regulation

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Abstract

In this paper, we present an overview of our shared experiences from a thirteen-year discovery and testing period in search of effective biological control agents for garlic mustard (*Alliaria petiolata* (M. Bieb.) Cavara & Grande). Our experiences during this time reflect much of the dialog, debate, dilemmas, and policy discussions occurring in biological control of weeds today. For example, in the last decade, the values that underpin biological control, as well as standard requirements and stakeholder perspectives have been in a state of flux. Many research programs fail to sustain funding for such long pre-release periods. Policy goals and acceptable safety criteria have changed. Moreover, the fundamental perception of garlic mustard as a pest is shifting, leading some to question whether garlic mustard is a driver of change in invaded habitats or rather a symptom of habitat disruption. If it is a symptom, this can shift the perception of the risks of biocontrol. In this shifting scientific and social milieu, land managers are still challenged by stakeholder demands for management of garlic mustard. Land managers have a responsibility to manage their sites for the purposes for which the land is preserved and have limited control, or no control over potential higher-level drivers such as earthworms, deer, climate change, and human population pressures. The intent of this presentation is to discuss these and other issues common to many who work in biological control, framing the discussion within our garlic mustard experience as the basis for dialog.
Background

Awareness and public interest in garlic mustard invasion of hardwood forests in the Midwest and Northeastern USA gained significant momentum in the 1980s with a series of key publications by Nuzzo (1991; 1996) and Nuzzo et al. (1996), culminating in the effort to develop a biological control program that started in 1998 with a broad base of support. At that time, available assessments ‘indicated that the only viable long-term option for successful management of garlic mustard is classical biological control’ (Blossey et al., 2001a). As part of the biological control project, a test plant list was developed, and CABI in Delémont, Switzerland contracted to conduct surveys and host specificity testing of candidate agents. Additional host specificity testing began in 2003 at the University of Minnesota, USA on plant species that were difficult to obtain or grow in Switzerland. Throughout this process stakeholders were engaged through various workshops (e.g. Skinner, 2005) and in the development (Blossey, 1999) and implementation of a long-term monitoring protocol for garlic mustard. The availability of pre-release data would allow us to gauge the impacts of anticipated biological control agent release(s) (Evans and Landis, 2007; Van Riper et al., 2010).

Gerber et al. (2009) summarized the biology and host-specificity results for the root-crown mining weevil (Ceutorhynchus scrobicollis Nerensheimer and Wagner) based on which, a petition for field release of the species was submitted in 2008 to the USDA APHIS TAG (United States Department of Agriculture, Animal and Plant Health Inspection Service, Technical Advisory Group). Based on the comments of reviewers, additional host testing was conducted from 2009 through 2011. Responses to reviewer comments to the 2008 petition and the results of additional host specificity testing were re-submitted to TAG in September of 2011.

Discussion

How safe is safe enough?

Typical of many weed biocontrol endeavors, the effort to release a biological control insect for garlic mustard in North America has been long and arduous. Thirteen years after officially initiating the research, we are awaiting TAG review of our latest submission. Much has changed during this time. For example, phylogenetic relationships among tribes within the Brassicaceae were redefined (Al-Shehbaz et al., 2006), necessitating continuous adaptation of our test plant list. Also, during this lengthy testing period, the concept of acceptable risk has changed. As common in risk assessments, “safe enough” is rarely achieved to the satisfaction of all stakeholders. One might conclude that agreement is rarely achieved now compared to biocontrol programs in decades past, as seen in papers presented at this conference. Lincoln Smith (in press) discussed an insect which has broad support for yellow starthistle (Centaura solstitialis L.) control, but ultimately was not approved for release. A retrospective review of past agents approved for release was presented by Hinz et al. (in press), exploring the possibility that most of these agents would not be approved in today’s regulatory climate in the USA.

In our case, C. scrobicollis did develop on the commercially grown watercress (Nasturtium officinale Ait. f.). Adult development on watercress was not consistent throughout tests conducted in different years. Moreover, C. scrobicollis development was only found when watercress was grown in artificial dryland mesocosms. Cultivated watercress is grown under water-saturated conditions (e.g., in running water). In refined host-specificity tests altered to simulate these growing conditions, C. scrobicollis was not able to complete its development on watercress. Additionally, C. scrobicollis has not been recorded as an economic pest, nor even in association with watercress in its native range where both co-exist, arguably the most comprehensive specificity testing possible.

While the overall host specificity package for C. scrobicollis on garlic mustard in North America suggests the ecological host range will be narrower than the physiological host range with the latter defined as development under highly artificial laboratory conditions, such data points could prove troublesome for the approval process. ‘Troublesome’ data points refer to data generated under circumstances which render the data suspect upon further scientific scrutiny. Once generated, however, these ‘troublesome’ data points do not go...
away. Despite subsequent work that more accurately reflects scientifically valid outcomes, the initial data remains in the body of evidence submitted for approval and often result in lingering concerns, particularly at the policy level, rather than at the scientific review process for biological control agents within USDA APHIS.

Is garlic mustard really that bad?

Another phenomenon that has evolved during our lengthy testing period is the notion that yesterday’s demonized pest may become today’s ecosystem services star. Apropos the papers presented at this symposium by Dudley et al. (in press) and Norton et al. (in press) discussed litigation over biological control of saltcedar (Tamarix spp.) impacting the southwestern willow flycatcher (Empidonax traillii extimus A.R. Phillips). Campaigns to disparage target invasives are common, prompting critical reviews reflecting on the fear-based language used with the public to generate support for control efforts (Gobster, 2005). Indeed, we used the Good, the Bad, and the Ugly campaign effectively in Minnesota to generate support for the biological control of purple loosestrife (Lythrum salicaria L.). Paradoxically, this terminology is now being used by opponents of biological control to describe the biological control agents. Warner & Kinslow (2011) explored this phenomenon more broadly in the context of manipulating risk communication to the public in the case of biological control of the strawberry guava tree (Psidium cattleianum Sabine) in Hawaii, resulting in an outcome different than intended by the scientific and conservation communities.

In the thirteen years since our effort began on garlic mustard, views of how we view this plant are evolving. Some studies have shown negative impacts of garlic mustard in invaded ecosystems while others found no impacts. Is garlic mustard a principal driver of detrimental impacts? Research showed that garlic mustard competition for light negatively impacted tree seedlings and annual herbaceous species (Anderson et al., 1996; Cipollini and Enright, 2009; Meekins and McCarthy, 1999), altered nutrient levels (Rodgers et al., 2008), and was toxic to arbuscular mycorrhizal fungi which could result in altered nutrient and water acquisition by many native species (Callaway et al., 2008; Cipollini and Gruner, 2007; Roberts & Anderson, 2001). Of concern to the forest industry, research suggested garlic mustard negatively impacted desirable tree seedlings (Stinson et al., 2006).

Alternatively, is the presence of garlic mustard merely a symptom of a response to higher-level changes? Indeed, garlic mustard often is observed in disturbed areas that lack native cover (Trimbur, 1973; Nuzzo, 1991; Van Riper et al., 2010). Recently it has been proposed that the action of deer and earthworms facilitate garlic mustard invasion (Blossey et al., 2005; Knight et al., 2009; Nuzzo et al., 2009). Deer herbivory on natives can create disturbed microsites that promote dispersal of garlic mustard seeds (Anderson et al., 1996). Loss of native plants may create suitable conditions for garlic mustard invasion through increased light levels, moisture, and nutrient availability (Anderson et al., 1996) and decreased litter levels (Trimbur, 1973), as well as through anthropogenic effects such as erosion.

Who is the driver?

If garlic mustard is not the principal driver of negative impacts, some on our team propose that we should focus efforts on the higher-level drivers (e.g., deer and earthworms), not the symptoms (e.g., garlic mustard). Such ideas are gaining support in the ecological literature where for example, Davis (2011) argued that species such as garlic mustard do not pose as big a threat as scientists think. Some are finding evidence that native insects impacted by garlic mustard may be adapting to it (Keeler and Chew, 2008). As a result, after a decade of testing, we have reached the juncture where our group is discussing whether we should release C. scrobicollis even if approved by TAG.

Exotic earthworms are widely discussed relevant to invasion in forest ecosystems (Nuzzo et al., 2009) and once established, few, if any management options exist to remove them. There has long been evidence about the negative impacts of deer on native plants (e.g., Hough, 1965; Tilghman, 1989; Diamond, 1992). However, limiting deer populations is difficult. State natural resource agencies both promote deer for hunting and as an income generator via hunting permits, while concomitantly expending resources to remove deer or to install exclusion devices to promote regeneration of tree species impacted
by deer browse. Neither of these factors is likely to change significantly in the near term. Also, it is not clear how the public would react to deer herd reductions to the low level required to reduce disturbance to a degree that may stop the invasion of plants like garlic mustard.

What is involved if land managers were to shift from managing garlic mustard to instead managing higher-level drivers? Figure 1 shows the relative geographic scale and management difficulty of several drivers that impact invasive species. This concept was adapted from a CABI Biosciences schematic depicting the centrifugal phylogenetic method. This driver schematic assumes garlic mustard as a symptom, not a driver. As we move out from the center, the geographic scale of the potential negative impact of the driver, and concomitantly, the difficulty in altering that impact increases. Earthworms are problematic, but at present are less widely distributed in the Midwest USA compared to deer. As we move to a wider geographic scale, anthropogenic effects such as pollution (e.g., nutrient loading, sediment runoff, etc.) and more broadly, climate change are clearly drivers of negative environmental change. Managing drivers such as climate change is distinctly long-term and the outcome uncertain. Ultimately, it is people and the resultant impact of our lifestyles and actions that is the overarching driver. Changing any of these on a scale to reduce negative impacts to ecosystems is a daunting endeavor, especially for a land manager.

**Will garlic mustard go away?**

During the time invested to find a biological control agent for garlic mustard, some members of our team have observed a decline in long-standing populations of garlic mustard absent the introduction of a biological control agent (Blossey and Nuzzo, in press). Perhaps we are just seeing the beginning of a decline in garlic mustard populations in North America, or are these population density fluctuations, related to climate cycles reflecting the natural ebb and flow of invasive species? If populations do significantly decline, will they resurge and expand to a point where we have populations of garlic mustard that are even more widely dispersed?

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**Centrifugal ‘Driver’ Model**

**For Garlic Mustard**

![Centrifugal driver model diagram](image_url)

Figure 1. The centrifugal driver model. An adaptation of a CABI diagram depicting the centrifugal phylogenetic method of Wapsphere (1974).
Additionally, would there be a benefit to uninvaded communities if a biocontrol agent could avoid a boom and bust cycle of garlic mustard?

More broadly, the field of ecology is exploring fluctuations in population densities of invasive species (Simberloff and Gibbons, 2004, Ahern et al., 2010). In the experiences of an Extension State Weed Scientist at the University of Minnesota (Becker), it is well known that species shift, population densities ebb and flow, and weed patches move around on the landscape. Landscape-scale changes in problem species in agricultural systems are driven by what weed scientists call the 'big hammers'; typically system-wide shifts in tillage, fertility, periodicity of operations, or the periodic dominance of one herbicide mode of action in the marketplace. An example of dramatic population fluctuations that may inform invasions that dominate the landscape and then moderate, was the effort in the USA to domesticate the native common milkweed (Asclepias syriaca L.) during World War II to produce floss (pappi) to fill life jackets when imports of goose down were blocked. Common milkweed in North America can be found throughout a broad habitat range. As it naturally occurs, common milkweed remains at low population densities and scattered across the landscape. In attempts at domestic production, when planted in monocultures in fields, density-dependant diseases quickly became an impediment to successfully growing the crop in many locales, and in many cases resulted in abandonment of fields. Experienced weed scientists often recount such phenomena, but as is often the case with experiential knowledge, it is seldom documented in peer-reviewed journal articles. Similar to the disease limiting phenomena seen in milkweed, we have observed that Canada thistle populations approaching monotypic stands decline after six to seven years due to generalist pathogens Fusarium and Pythium resulting in reduced population densities that are relatively dispersed.

Garlic mustard is a biennial species cycling in a perennial system. Sustaining a population is wholly dependent on constant regeneration of rosettes from seedlings. Seedling regeneration depends on disturbance and is subject to episodic widespread seedling mortality. At some of our garlic mustard monitoring sites in Minnesota, we see cycles where either the seedling/rosette or the flowering second-year growth stage dominate in a given year, while at other sites they occur simultaneously (Van Riper et al., 2010). By its biennial nature, garlic mustard populations will fluctuate dramatically, and in extreme climatic events, may even skip population cycles altogether, only to resurface in the future. Thus, multiple forces are at work resulting in garlic mustard populations that are very dynamic. Our challenge is to determine the long-term trends, and what that means within the construct of our original justification for biological control of garlic mustard.

Conclusions

Many on our team were also part of the biological control effort of purple loosestrife in North America, informing our approach to biological control of garlic mustard. Many of the same stakeholders and funding sources were used in both efforts, and the perceived success of purple loosestrife biocontrol resulted in built-in enthusiasm for the garlic mustard effort. For example, the network of pre-release garlic mustard monitoring sites included many managers who were...
cooperators on the purple loosestrife effort. Blossey et al. (2001b) was in part a response to criticisms of the purple loosestrife biological control effort. Yet almost two decades after the release of *Galerucella* spp. for biological control of purple loosestrife, science has not settled the debate surrounding biological control of that invasive species (Lavoie, 2010). More studies are being proposed to answer the next set of garlic mustard research questions. We are on the cusp of gaining approval for release of *C. scrobicollis*, but are debating similar questions that are still debated for purple loosestrife. Experience indicates that scientific discourse will be unable to expeditiously address the complex interactions to manage higher-level drivers, nor quickly settle the more direct question of whether invasion by garlic mustard negatively impacts native ecosystems.

So, considering the debate over whether garlic mustard negatively impacts forest ecosystems and whether it is only present because of higher-level drivers, what can land managers do in response to public demands for action? As is the case for many pest problems, the default action is to treat the symptoms – in this case an invasive weed that has become abundant. This option is something we can do and can measure the success of in terms of cost and effectiveness, providing justification to those who fund such programs. Control of invasive, noxious weeds is often required via regulated weed laws in the USA. Managing higher-level drivers arguably might be the most efficacious and efficient approach; however, it would involve a higher degree of complexity, is more difficult to implement, and is an approach that takes a long time to provide results, thus, making it more challenging to garner and maintain support.

One of our team members summed it up this way: We should address the symptoms, i.e., control garlic mustard if it: 1) provides additional time to address root causes, 2) prevents degradation in the meantime, 3) poses minimal risks, and 4) does not clearly jeopardize a long term solution. Doing so may spare uninvaded and minimally invaded habitat in the Midwest the upheaval of a garlic mustard invasion. This may not be true in parts of the northeast. Midwest ecosystems could benefit from delay or reduction of garlic mustard invasion considering our host specificity data suggest minimal risk.

We are left with a dilemma. On one hand, we must consider the implications of releasing an organism against a pest that may not be the root cause of detrimental changes. This would be an especially egregious error if the biological control agent caused unintended nontarget damage in the future. On the other hand, we must also consider the implications of not releasing a biological agent deemed safe for a target that many stakeholders feel has significant negative impacts. Managers may not be able to eliminate earthworms and deer, but biocontrol could give them a tool to reduce one stressor to the system: garlic mustard. Not releasing a biocontrol agent is particularly problematic if future work confirms significant impacts on forest ecosystems, and populations do not undergo a natural decline but rather persist across the landscape. Considering the ongoing controversies regarding biological control of weeds, we must also reflect on the implications these two scenarios may have for the future of biological control of weeds, both from a policy and funding viewpoint.

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