Garlic Mustard

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Pest Status of Weed

Garlic mustard, *Alliaria petiolata* (M. Bieb.) Cavara and Grande, (Fig. 1), a cool-season, shade-tolerant, obligate biennial herb, is currently one of the most serious invaders in forested areas of the northeastern and midwestern United States. *Alliaria petiolata* is one of the few non-indigenous herbaceous species able to invade and dominate the understory of North American forests. Garlic mustard is not known as a weed on other continents.

Figure 1. Garlic mustard plant. (Photo by V. Nuzzo.)

Nature of Damage

Economic Damage. *Alliaria petiolata* is a weed of natural areas and little direct economic damage has been described or documented. The invasion potential of *A. petiolata* and its ability to cause changes in forest productivity has not been assessed.

Ecological Damage. Little long-term research has been conducted to document the impact of garlic mustard on native ground layer vegetation. However, sites invaded by *A. petiolata* frequently have low native herbaceous richness (Fig. 2) and garlic mustard has been implicated as the cause of this low diversity (White *et al*., 1993; Anderson *et al*., 1996; McCarthy, 1997; Meekins and McCarthy, 1999). Garlic mustard invades sites independent of presence or cover of native species, and species-rich sites are more likely to be invaded than species-poor sites (Nuzzo, unpub. data). Once established, *A. petiolata* becomes a permanent member of the community, steadily increasing in presence but with large annual fluctuations in cover and density (Byers and Quinn, 1998; Nuzzo, 1999; Meekins, 2000). Long-term presence of garlic mustard was associated with a significant decline in cover of native perennial herbaceous species (Nuzzo, unpublished data). Phytotoxic chemicals produced by *A. petiolata* may interfere with growth of native species, potentially through inhibition of mycorrhizal activity (Vaughn and Berhow, 1999).

Figure 2. Dense garlic mustard. (Photo by V. Nuzzo.)

Presence of garlic mustard interferes with oviposition of the rare native butterflies *Pieris napi oleraceae* Harris and *Pieris virginiensis* W. H. Edwards (Lepidoptera: Pieridae). The native hosts of *P. napi oleraceae* and *P. virginiensis* are toothworts *Cardamine concatenata* [*Dentaria laciniata*] (Michx.) O. Schwarz and *Cardamine* [*Dentaria*] *diphylla* (Michx.) A. Wood, Brassicaceae. Eggs laid by females hatch but larvae are unable to complete development on garlic mustard (Chew, 1981; Porter, 1994;

Huang *et al*., 1995; Haribal and Renwick, 1998).

Extent of losses. Lack of long-term data makes quantification of direct losses impossible.

Geographical Distribution

By 2000, *A. petiolata* was most abundant in the northeastern and midwestern United States, ranging from southern Ontario, south to Georgia, Arkansas, and Kansas. Isolated occurrences are known from Utah and Colorado, and populations established in the Pacific Northwest appear to be spreading.

Background Information On The Pest Plant

Taxonomy

In North American floras, *A. petiolata* was often referred to as *Alliaria officinalis* Andrz; other names found in older floras include *Alliaria alliaria* L. (Britton), *Sisymbrium alliaria* Scop., *Sisymbrium officinalis* D. C. (not *S. officinale*), and *Erysimum alliaria* L.

Biology

Basal leaves are dark-green and kidney-shaped with scalloped edges (6 to 10 cm diameter). Stem leaves (3 to 8 cm long and wide) are alternate, sharply toothed, triangular or deltoid, gradually reduced in size towards the top of the stem. All leaves have pubescent petioles 1 to 5 cm long. In spring, new leaves produce a distinct garlic odor when crushed, which fades as leaves age. Plants usually produce a single flower stalk, although up to 12 separate flowering stalks have been reported for robust plants. Flowers are produced in spring in terminal racemes. Some plants produce additional axillary racemes in mid-summer. Flowers are typical of the mustard family, consisting of four white petals that narrow abruptly at the base, and six stamens, two short and four long. Flowers average 6 to 7 mm in diameter, with petals 3 to 6 mm long. Fruits are linear siliques, 2.5 to 6 cm long and 2 mm wide, held erect on short (5 mm), stout, widely divergent pedicels. Individual plants produce an average of 22 siliques, arranged alternately on both sides of a papery sinus and containing up to 28 seeds. Seeds are black, cylindrical (3 by 1 mm) and transversely ridged, and range in weight from 1.62 to 2.84mg. Chromosome number of $2n$=36 has been recorded for European, and $2n$=24 for North American and European individuals (Cavers *et al*., 1979).

Alliaria petiolata is an obligate biennial plant with a phenology typical of cool-season European plants. *Alliaria petiolata* grows rapidly in late fall and early spring when native species are dormant (Cavers *et al*., 1979; Anderson *et al*., 1996), and all individuals that overwinter successfully will flower and subsequently die (Cavers *et al*., 1979; Bloom *et al*., 1990; Byers and Quinn, 1998; Meekins, 2000). Flowers open as early as April and are insect pollinated, but plants can self-pollinate (Cruden *et al*., 1996). Seed production varies according to habitat conditions (Byers and Quinn, 1998; Nuzzo, 1999; Susko and Lovett-Doust, 2000), but can be as high as 7,900 seeds for robust plants (Nuzzo, 1993). Seeds require 50 to 105 days of cold stratification (1 to 10°C) (Byers, 1988; Baskin and Baskin, 1992; Meekins and McCarthy, 1999), resulting in a dormancy period of 8 months in southern, and 8 to 22 months in northern, locales (Cavers *et al*., 1979; Byers, 1988; Baskin and Baskin, 1992; Solis, 1998). Garlic mustard forms a short-lived seed bank (Roberts and Boddrell, 1983; Baskin and Baskin, 1992). Seeds germinate in early spring (Cavers *et al*., 1979; Baskin and Baskin, 1992) with seedling densities as high as 20,000/m^2 (Trimbur, 1973; Anderson *et al*., 1996). First year rosettes are sensitive to summer drought (MacKenzie, 1995; Byers and Quinn, 1998; Meekins, 2000) and 60 to 90% die by fall (Anderson *et al*., 1996; Byers and Quinn, 1998).

Analysis of Related Native Plants in the Eastern United States

Alliaria petiolata belongs to the Brassicaceae with 43 different genera represented in the northeastern United States alone (Gleason and Cronquist, 1991). *Alliaria petiolata* is the only species of the genus *Alliaria* in North America (Gleason and Cronquist, 1991). Many introduced species are of economic interest; mustards (*Brassica*) are the most important genus. Among native taxa, *Cardamine* [*Dentaria*] are particularly diverse and grow in the same habitats as *A. petiolata*. Other native genera include *Cakile, Lepidium, Subularia, Draba, Lesquerella, Leavenworthia, Sibara, Arabis, Rorippa, Barbarea, Iodanthus, Erysimum,* and *Descurainia*; all other 29 genera are introduced (Gleason and Cronquist, 1991).

History of Biological Control Efforts in the Eastern United States

Research in North America and Europe began in 1998 with field surveys for potential control agents.

Establishment of Area of Origin of Weed

Alliaria petiolata is native to Europe, ranging from England to Sweden to the western regions of the former USSR (Turkestan, northwestern-Himalayas), India and Sri Lanka, and south to Italy and the Mediterranean basin (Tutin *et al*., 1964; Cavers *et al*., 1979; Hegi, 1986). The species has been introduced to New Zealand (Bangerter, 1985), Canada (Cavers *et al*., 1979) and the United States (Gleason and Cronquist, 1991; Nuzzo, 1993). In North America, *A. petiolata* was first recorded on Long Island, New York in 1868 (Nuzzo, 1993).

Areas surveyed for Natural Enemies

Literature surveys for natural enemies of garlic mustard were conducted in Europe and North America. Field sites in Germany, Switzerland and Austria were investigated for their herbivore fauna associated with garlic mustard in 1998 and 1999 (Hinz and Gerber, 1999). Field sites in eastern North America were surveyed in spring and summer 2000.

Natural Enemies Found

A literature survey followed by field investigation in western Europe revealed that 69 insect herbivores and seven fungi are associated with garlic mustard in Europe (Hinz and Gerber, 1998). The most important groups of natural enemies associated with garlic mustard were weevils (Curculionidae), particularly the genus *Ceutorhynchus*, leaf beetles (Chrysomelidae) and butterflies and moths (Lepidoptera). Most of these species are not considered sufficiently host-specific for introduction to North America.

Two stem-mining weevils, a stem-mining fly, a leaf-mining fly, a scale insect, two fungi, and aphids (taxonomic identification for all species is pending) were found attacking garlic mustard in North America. However, their attack was of little consequence to plant performance or reproduction of garlic mustard (Blossey and Nuzzo, unpub. data).

Host Range Tests and Results

Preliminary investigations of the host range of several potential control agents were conducted in 1999 (Hinz and Gerber, 2000) and continued in 2000. Among several non-target species tested, *Rorippa* spp. were identified as potential hosts for a flea beetle. Particular emphasis during host specificity screening will be on native forest understory species associated with garlic mustard in North America. Host range tests will continue through 2003 at CABI Bioscience Centre in Switzerland.

Releases Made

No releases of agents have yet been made against garlic mustard.

Biology and Ecology of Key Natural Enemies

Based on information on their restricted host range and their damage, five weevils and one flea beetle were selected as potential biological control agents for garlic mustard (Blossey *et al*., 2001). Descriptions of their life history and ecology are based on Hinz and Gerber (2000).

***Ceutorhynchus alliariae* Brisout and *Ceutorhynchus roberti* Gyllenhal (Coleoptera: Curculionidae)**

The two weevil species *Ceutorhynchus alliariae* Brisout and *Ceutorhynchus roberti* Gyllenhal (Fig. 3) share similar life history features and occupy the same niche on their host plant. Adults feed on leaves; larvae develop in stems and leaf petioles of garlic mustard. Both species are univoltine. Adults can be distinguished morphologically using coloration of their tarsi, but no reliable features distinguish immature stages (Hoffmann, 1954; Dieckmann, 1972; Hinz and Gerber, 2000). Both species show widely overlapping distributions in Europe (Hinz and Gerber, 2000) although *C. roberti* is the only species reported from Italy (Abazzi and Osella, 1992).

Figure 3. *Ceutorhynchus roberti*.
(Photo by H. Hinz and E. Gerber.)

Adults of both species overwinter in soil and leaf litter, and become active simultaneously in early spring. In Europe, oviposition begins around mid March and continues until mid to late May. Eggs are laid individually (*C. alliariae*) or in clusters of up to nine eggs (*C. roberti*) into elongating stems and leaf petioles of garlic mustard. Larvae hatch after one to three weeks and feed internally on the host plant. Mature third instar larvae leave the host plant to pupate in the soil. Larval development from egg to mature larvae takes about seven weeks with new generation adults emerging in June and July.

Attack rates in Europe ranged from 48 to 100% of shoots at various field sites investigated during 1998 and 1999, with an average of 2 to 11 larvae/shoot (Hinz and Gerber, 2000). High attack rates appear to reduce seed production of *A. petiolata*; at densities of 20 to 30 larvae/shoot premature wilting and nearly complete prevention of seed production was observed.

Ceutorhynchus scrobicollis Nerensheimer and Wagner (Coleoptera: Curculionidae)

During recent surveys, *Ceutorhynchus scrobicollis* Nerensheimer and Wagner (Fig. 4), a univoltine root mining weevil, occurred only in eastern Germany and eastern Austria (Hinz and Gerber, 2000), but the species is also reported from eastern France and Italy (Colonnelli, 1987; Schott, 2000). Adults emerge in May and June, consume leaves for a brief period, followed by summer aestivation. In Europe, oviposition begins in mid September and continues through to spring. Eggs are laid mainly into leaf petioles and into the leaf surface of rosettes. Early instars mainly mine petioles but also growing points of rosettes. The majority of mature larvae feed in root crowns. Larvae overwinter and continue feeding on garlic mustard plants and leave the host plant in spring to pupate in the soil. Within the European distribution of *C. scrobicollis*, attack rates ranged from 50 to 100% of plants. On average 4 to 8 larvae complete development within a single plant, occasionaly many more. Attacked plants appear water stressed, have reduced seed production and at high infestations, dry up prematurely.

Figure 4. *Ceutorhynchus scrobicollis*.
(Photo by H. Hinz and E. Gerber.)

Ceutorhynchus constrictus (Marsham) (Coleoptera: Curculionidae)

Ceutorhynchus constrictus (Marsham) is a univoltine weevil. It is the most widespread of the *Ceutorhynchus* species associated with garlic mustard and is commonly found all over western and central Europe (Dieckmann, 1972). Adults feed on leaves and larvae feed on developing seeds (Fig. 5). Adults appear in April to feed and mate. Oviposition starts once *A. petiolata* begins to produce siliques (seed pods) in May and June. A single female may produce well over 150 eggs during a season. Larvae feed on developing seeds during June and July with each larva consuming 1 to 2 seeds before leaving the silique to pupate in the soil. Mature larvae form an earthen cocoon, pupate, and fully developed adults overwinter in the soil until the following spring. Although the species was found at all field sites in our surveys, attack rates were generally low with only 0.3 to 6.4% of seeds attacked in southern Germany and Switzerland.

Figure 5. *Ceutorhynchus constrictus* and attacked seeds. (Phot by H. Hinz and E. Gerber.)

Ceutorhynchus theonae Korotyaev (Coleoptera, Curculionidae)

This newly described species was collected in Daghestan, Russia in spring 2000 and shipments into quarantine at CABI, Switzerland were arranged. Preliminary investigations conducted in Switzerland confirm that the species is attacking seeds of garlic mustard. The biology of *C. theonae* appears similar to *C. constrictus*, however, feeding by *C. theonae* appears more damaging compared to *C. constrictus*. This new species will be included in the host specificity testing procedure if sufficient adults can be obtained and rearing methods be developed.

Phyllotreta ochripes (Curtis) (Coleoptera: Chrysomelidae)

Figure 6. Phyllotreta ochripes. (Photo by H. Hinz and E. Gerber.)

The flea beetle *Phyllotreta ochripes* (Curtis) (Fig. 6) attacks leaves (adults) and roots (larvae) of bolting *A. petiolata* plants as well as of rosettes. The species has at least a partial second generation and is potentially multivoltine. *Phyllotreta ochripes* ranges widely over most of Europe and parts of northwestern Asia (Gruev and Döberl, 1997). During field surveys in Switzerland, Germany, and Austria, *P. ochripes* was commonly found at all field sites investigated. In Europe, adults overwinter in the leaf litter and were found feeding on garlic mustard rosettes as early as the beginning of March. Females lay an average of 280 eggs from the end of April until the beginning of August. Eggs are laid into the soil close to root crowns and larvae usually mine just below the epidermis of roots or root crowns of bolting plants and rosettes. Mature larvae pupate in the soil and adults emerge by the end of June. Emergence of adults continues until the end of September. Development from first instar to adult takes 30 to 65 days. At present, little is known about the impact of *P. ochripes* on plant performance.

Evaluation of Project Outcomes

Establishment and Spread of Agents

No introductions have occurred.

Suppression of Target Weed

Not applicable.

Recovery of Native Plant Communities

Not applicable.

Economic Benefits

Not applicable.

Recommendations for Future Work

The present focus in the garlic mustard biological control program is on evaluation of host specificity and impact of potential agents identified in Europe (Blossey *et al*., 2001).

Description of Planned Work

The host specificity of all six insect species proposed as potential biological control agents for *A. petiolata* will be evaluated in Europe before any introductions are proposed. Host-specificity tests will follow the testing sequence suggested by Wapshere (1989). A sequence of different testing procedures will be used, involving about 50 different test plant species. Special attention will be given to native North American crucifers (especially *Cardamine* [*Dentaria*] and *Rorippa* spp.) cultivated crucifers (cabbages), and native plant species growing in the same habitats, particularly spring ephemerals. The five *Ceutorhynchus* species selected as potential biological control agents for garlic mustard are reported to be monophagous (Dieckmann, 1972) (*C. theonae* is assumed to be monophagous; B. Korotyaev, pers. comm.). *Phyllotreta ochripes* was reported to complete larval development on both *A. petiolata* and *Rorippa amphibia* (L.) Besser (Doguet, 1994). Host specificity investigations confirmed these results and successful larval development occurred on eight additional plants including *Rorippa* spp. and *Brassica* spp. (Hinz and Gerber, 2001). Several North American native *Rorippa* species occur through the North America distribution of *A. petiolata*, including *Rorippa sinuata* (Nutt.) A. S. Hitchc., *Rorippa sessiliflora* (Nutt.) A. S. Hitchc., *Rorippa palustris fernaldiana* (Butters and Abbe) Stuckey, *Rorippa palustris hispida* (Desv.) Rydb., *Rorippa curvipes* Greene, and *Rorippa obtusa* (Nutt.) Britt. (Fernald, 1970; Voss, 1985; Gleason and Cronquist, 1991). Many of these plant species will be incorporated into the host specificity testing to assess the potential of *P. ochripes* and of the *Ceutorhynchus* species to attack these North American plants.

Impact studies are planned to test the assumption of competition or of cumulative effects of herbivores attacking the same plant (Harris, 1991; Masters *et al*., 1993; Denno *et al*., 1995; McEvoy and Coombs, 1999). Results from these experiments will help determine, in combination with host specificity results, which species to propose for introduction to North America.

Management of garlic mustard or any other invasive plant aims to protect or restore native ecosystem properties. An important aspect of the biological control program is the collection of baseline data before any introduction of control agents occurs. The standardized protocol will incorporate measures of (1) garlic mustard abundance, (2) abundance and impact of biological control agents, and (3) changes in native plant communities and associated fauna. We anticipate a protocol sophisticated enough to allow rigorous statistical analysis, yet simple enough to allow widespread use by natural areas managers.

Anticipated Effects of Agents

At present little information on the impact of the potential control agents on garlic mustard performance is available. Attack by single or multiple herbivores is anticipated to reduce the competitive ability of garlic mustard in North America. We also anticipate that combinations of agents attacking different plant parts will be superior to the impact of a single species. We will use such predictions to develop a framework for cross-continental comparisons of plant and insect population dynamics.

Techniques to Be Used

Host specificity screening techniques are widely standardized and we will follow guidelines established in the literature and by USDA (Wapshere,1989; USDA, 1999).

Other Comments

Combining long-term monitoring, experimental research, and evaluation will provide a framework for improving management of invasive plants using biological control. In addition, such investigations will continue to improve the scientific basis and predictive ability of biological weed control.

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