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IMPACTS OF HERBIVORES AND PLANT COMMUNITIES ON
ESTABLISHMENT AND SPREAD OF *ALLIARIA PETIOLATA*
(GARLIC MUSTARD) IN MICHIGAN

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IMPACTS OF HERBIVORES AND PLANT COMMUNITIES ON ESTABLISHMENT AND SPREAD OF *ALLIARIA PETIOLATA* (GARLIC MUSTARD) IN MICHIGAN

By

Jeffrey Adam Evans

A THESIS

Submitted to
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ABSTRACT

IMPACTS OF HERBIVORES AND PLANT COMMUNITIES ON ESTABLISHMENT AND SPREAD OF *ALLIARIA PETIOLATA* (GARLIC MUSTARD) IN MICHIGAN

By

Jeffrey Adam Evans

Alliaria petiolata (garlic mustard) (M. Bieb) Cavara and Grande) is shade-tolerant biennial forb of European origin that is now widespread and invasive in North American forest communities. As conventional control efforts against *A. petiolata* have failed, research efforts are now focused on developing classical biological controls. The goal of my research was to explore and interpret the biology and invasion ecology of *A. petiolata* in Michigan in support of current and future control efforts. *Alliaria petiolata* populations were shown to be expanding at all sites studied with 59% of initially uninvaded sampling quadrats becoming invaded after two years. 84.5% of the quadrats with *A. petiolata* showed evidence of herbivore browsing or other damage. However, damage estimates were very low (2.9% of leaf area damaged) and were not correlated with *A. petiolata* survival or fecundity. *Alliaria petiolata* may negatively impact native species where it becomes dominant as it has at one site where it represented 57% of the total vegetation. Native and exotic species richness of the sites were positively correlated (Spearman r_s = 0.9729), but the relationship of quadrat-scale native species richness to *A. petiolata* presence or absence reversed across a gradient from species-rich to species-poor sites (P = 0.0087). This suggests that neither biotic resistance nor enhancement alone sufficiently explains *A. petiolata*'s invasion processes. Rather, *A. petiolata* appears to make tradeoffs between its competitive ability and stress tolerance under different conditions.

For Courtney

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Thank you all,

Jeff Evans

East Lansing, February 23, 2006

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With the invasion of animals and plants…, it is the successful species that are concerned. But there are enormously more invasions that never happen, or fail quite soon or even after a good many years. They meet with resistance. It is this resistance, whether by man or by nature or by man mobilizing nature in his support, that has now to be examined: what it is and how it can be understood and when necessary manipulated and increased when desired.

Charles S. Elton

1958

We can outcompete with anybody.

George W. Bush

Bay Shore, New York, Mar. 11, 200

Chapter 1

BIOLOGICAL INVASION BY *ALLIARIA PETIOLATA* (BIEB.) CAVARA AND GRANDE: HISTORY, ECOLOGY, AND MANAGEMENT PROSPECTS

Jeffrey Adam Evans

ABSTRACT

Alliaria petiolata (garlic mustard) (M. Bieb) Cavara and Grande) is a shade-tolerant biennial forb of European origin that is now widespread and invasive in forest communities from the east coast of North America to Alaska. *Alliaria petiolata*'s owes its success as an invader in part to its high fecundity and plastic response to changing environmental conditions. Plants can grow to maturity under light conditions ranging from the shade of closed forest canopies to near full-sun conditions. Flowers are typically insect pollinated but are facultatively selfing if no pollinators visit them. Individual plants can produce thousands of seeds, and fecundity is reduced only by 46% when 100% of leaves are removed. Cutting *A. petiolata* stems effectively kills second year plants, but if plants are cut after *A. petiolata* has flowered seeds still reach maturity on the cut stalks. Seed longevity in the soil can be at least eight years, implying that any successful control efforts will need to be sustained on at least a decade scale until the seed bank is exhausted. Although seedling and rosette survival rates are low at high densities, they are substantially higher where populations are sparse. Thus, *A. petiolata* is an effective colonizer of new areas. Allelochemicals produced in *A. petiolata*'s roots and leaves effectively suppress germination of competitors' seeds and prevent germination of arbuscular mycorrhizal spores, thereby disrupting important mutualisms upon which many later-successional native species are dependent. Other defensive chemistry deters specialized herbivore feeding in *A. petiolata*'s introduced range, although a broad community of specialists and generalists feed on it in Europe. Conventional control efforts including cutting, pulling, prescribed fire, and herbicides have proven ineffective against all but the smallest infestations. Research efforts are now focused on developing

classical biological controls for potential future releases, with a group of four weevils (Coleoptera: Curculionidae) in the genus *Ceutorhynchus* now appearing the most promising. *Alliaria petiolata*'s success as an invader results from its combined demographic, phytochemical, and physiological properties, and effective future control strategies will need to successfully address each of these. The goal of my research is to explore and interpret the biology and invasion ecology of *A. petiolata* in Michigan in support of current and future efforts to control its spread. Specific research objectives are addressed in subsequent chapters.

INTRODUCTION

Biological invasions are a leading threat to global biodiversity (Wilcove et al. 1998). As many as 50,000 non-indigenous species have been introduced to the United States alone (Pimentel et al. 2000), but globalization of economies, increased human travel, and the task of regulating new introductions have torn down longstanding geographical barriers to species dispersal and place this number within the realm of possibility. Of these introductions, approximately 5000 plant species have become established in natural systems and now comprise nearly one third of all wild flora (Pimentel et al. 2000 and sources therein). The full scope of this phenomenon and its potential consequences for human well being and natural systems alike are not fully understood. Increases in efforts to understand and address biological invasions (Figure 1) have led to improved management approaches to invasions. Continued introductions and developing fields within the sciences have highlighted the need to address invasions across scales from molecular to global and with increasing analytical complexity. While some invasions may pose substantial threats to ecosystems and resources required by humans, they also present a rich arena in which to explore the dynamic processes of community assemblage and structure, trophic interactions, and changes in each of these across spatial and temporal gradients. I have reviewed the growing body of literature related to the introduction and invasion of *Alliaria petiolata* (Bieb.) Cavara and Grande (Brassicaceae). From this I have attempted to interpret the dynamics and characteristics that drive and limit its invasion process locally and evaluate its potential impacts on native communities.

STUDY SPECIES

NOMENCLATURE AND ANTHROPOGENIC USES

Alliaria petiolata (Bieb.) Cavara and Grande (Brassicaceae), is a globally distributed, shade tolerant, cool-weather obligate biennial that is a frequent component of forest understory and edge communities. Also know as garlic root, garlicwort, hedge-garlic, jack-by-the-hedge, jack-in-the-bush, mustard root, poor-man's-mustard, and sauce-alone, the most commonly used name in North America is "garlic mustard" (Nuzzo 1993b, Society for Economic Botany 1998). Most common names refer to the distinctive garlic or onion odor of crushed leaves, its historic use as an edible green and cooking herb, and its common distribution in edge habitats. *Alliaria petiolata* is also used in traditional remedies for numerous ailments. These include use as an expectorant, a digestive aid, a subdofic (a medicine that causes sweating) and for treatment of wind colic (pain or obstruction of the colon). *Alliaria petiolata* has higher vitamin C content by weight than oranges and higher vitamin A content than spinach (Cavers et al. 1979). Older scientific names include *Alliaria alboi* Sennen, *Alliaria alliacea* Britt. et Rendle, *Alliaria alliaria* Huth, *Alliaria matthioli* Rupr.,*Arabis petiolata* M.B., *Crucifera alliaria* E.H.L. Krause, *Erysimum alliaceum* Salisb., *Erysimum alliaria* L., *Hesperis alliaria* Lam., *Sisymbrium alliaria* Scop., *Sisymbrium officinalis* DC, and in North America, *Alliaria officinalis* (Nuzzo 1993b, Hinz and Gerber 1998, Kerguélen 1999).

ALLIARIA PETIOLATA LIFE CYCLE

Alliaria petiolata is an obligate biennial or winter annual in the Brassicaceae (Cavers et al. 1979) that occurs primarily in temperate forest understory and edge communities. First and second year plants are typically not intermixed within localized patches, creating an effective alternation of generations in patches annually in newly established populations. Over time, the seed bank moderates this effect somewhat and first and second year plants are sometimes found in mixed patches. Strong suppression of seedlings by adults keep the generations segregated locally in many areas, though (Winterer et al. 2005). Seedlings that germinate under cover of second year plants have very high mortality. In areas where it is invasive, *A. petiolata* spreads as a moving front as satellite populations ahead of the core establish and fill out. This front typically advances and retreats during alternate years advancing as much as 36 m and retreating by up to 18 m during different years because of its biennial lifecycle. The net rate of spread is usually positive, with an average advance of 5.4 m/y (Nuzzo 1999).

First Year Plants

Seed and Germination Biology

Seeds of *A. petiolata* require cold stratification prior to germination. Baskin and Baskin (1992) studied the germination biology of *A. petiolata* and found that germination rates are highest under natural, fluctuating winter temperatures ranging between 0.5 and 10°C. They report germination rates as high as 96 - 100% for buried seeds in an unheated greenhouse. Germination peaks when mean daily temperatures range between –1.0 and 8.1°C. This finding is significant as seedlings of *A. petiolata* emerge at the end of winter or in very early spring while the forest canopy is open and before other forbs germinate and begin growing. Consequently, *A. petiolata* germinates under high light conditions with little competition from other plants. *Alliaria petiolata* seedlings grow rapidly and form a low, tight canopy over the forest floor with densities as high as 20,000/m^2 (Trimbur 1973).

In Great Britain, most seeds germinate after one season of cold stratification (Roberts and Boddrell 1983). Seeds in Ontario, Canada, remain dormant for one to two years before germinating with only 5 - 9% of seeds produced in a given year emerging to form seedlings with only 2 - 4% of seedlings survive to flower (Cavers et al. 1979). Seeds can remain viable for up to five years after production with viability in Great Britain dropping off sharply after the first year to 1.4 - 24.1% in the second year and 0.1 - 1.5% in years three, four and five (Roberts and Boddrell 1983). With seed production as high as 107,580/m^2 (Cavers et al. 1979), even this low rate of germination after several years' dormancy could result in a substantial emergence of seedlings.

Seed mass in *A. petiolata* varies between populations up to eightfold, within populations from 2.5 - 7.5 fold, 2 - 3 fold within individual plants, and 1.4 - 1.8 fold within individual fruits(Susko and Lovett-Doust 2000a). Variation in seed mass is implicated in the timing of seedling emergence with smaller seeds germinating earlier than larger ones. This may be a combined effect of the thinner seed coat and higher surface to volume ratios of smaller seeds, both of which allow increased water absorption and thereby break seed dormancy earlier. Earlier emerging seedlings produce longer hypocotyls and grow taller than those from larger seeds, allowing them to partially shade seedlings that emerge later. Thus, small seed size in *A. petiolata* may be advantageous.

Seedlings and Rosettes

Emerging seedlings present cotyledons with blades averaging 6 mm long on petioles of equal length, and the hypocotyl averages 2 cm long. The first leaves are 1 - 5 cm diameter and roughly toothed on pubescent petioles. First year plants form low rosettes of dark purple to green, kidney shaped leaves with scalloped edges 2 - 12 cm in diameter on 3 - 10 cm long pubescent petioles (Cavers et al. 1979). The early season leaves produce a distinct garlic or onion odor when bruised, although its intensity decreases as the leaves age during the summer. Mortality is highest (>50%) during the seedling stage. Only 2 - 4% of seedlings that emerge will live to flower (Cavers et al. 1979).

Overwintering

First year *A. petiolata* plants overwinter as green rosettes and are photosynthetically active on days when the temperature is above freezing. Combined seedling and winter mortality is high. Nuzzo (1993a, 1993b, 1993c, 1996) showed that approximately 20% of rosettes survive the winter. Rosette densities in the spring average 30-80/m^2, although they can be as high as 450/m^2. About 9% of the variance between fall and spring rosette densities can be attributed to fall rosette density. A study of the variation in demographic rates of *A. petiolata* populations across southern Michigan is ongoing (Davis et al. 2005).

Second Year Plants

Growth and Description

Stem elongation in second year plants begins under high light conditions during spring before canopy trees leaf out. Growth is rapid during bolting, with plants in Illinois reported to increase in height an average of 1.9 cm/day (Anderson et al. 1996). Basal leaves of bolting and mature second year plants are the same as those of first year rosettes. Cauline leaves are 3-8 cm long on pubescent petioles and become gradually smaller towards the stem apex. Leaves are deltoid and roughly toothed. The stem is erect and typically glabrous or with few hairs and grows as tall as 1.5 m (Hinz and Gerber 1998).

Flowering and Pollination

Timing of flower bud production is approximately synchronous with bolting and occurs when plant height averages 7.5 cm (Anderson et al. 1996). Flowers are grouped into racemes at the apex of the stem and at some leaf axils. Mature flowers are white and average 4-7 mm across with 4 spatulate petals 3-6 mm in length and 4 green sepals. Each flower bears 4 long and 2 short sepals with one gland at the base of each pair of stamens (Cavers et al. 1979).

Anderson et al. (1996) described flower development in six stages: (a) bud 2 mm long with early development of white stripes along sepal margins; (b) bud 3 mm long with white stripe enlarged along sepal margins; (c) bud 3.3 mm long prior to pushing off of sepal cap (calyx cap) by the growing petals; (d) cap stage where calyx cap is pushed up the top of the petal as the petals expand - calyx cap covers flower for a short duration; (e) anthesis, during which calyx cap is shed, petals expand and unfold, and the anthers dehisce; (f) open flower stage when flower is completely open and pollen sacks are exposed.

Flowers are reflective in the ultraviolet range, which may serve to attract insect pollinators. Cruden et al. (1996) and Anderson et al. (1996) studied the pollination and breeding system of *A. petiolata* and reached contrasting conclusions. Whereas Cruden et al. (1996) found *A. petiolata in* Iowa to be facultatively xenogamous (flowers normally cross-pollinate, but are self fertile when pollinators are absent), Anderson et al. (1996) found populations in central Illinois to be primarily autogamous with the majority of pollination events occurring during the cap stage prior to anthesis. Flowers remain open for two and infrequently three days. Nectar production and insect visitor frequency peak on day one of flowering from 0915h to 1830h with the highest visitation rates from 1100h to 1600h (Cruden et al. 1996). Generalist pollinators are reported on *A. petiolata* in Illinois (Anderson et al. 1996) and include Diptera: Syrphidae, and Hymenoptera: Apidae, Andrenidae, Halictidae in Iowa (Cruden et al. 1996). Flowers in Iowa that are not visited by insect pollinators self-pollinate (Cruden et al. 1996). From 1330h of day one onward, stamens begin moving inward and eventually brush the anthers against the stigma where they deposit from 30 to 750 pollen grains. However, insect pollinators visited the majority of flowers at this site where self-fertilization is apparently a secondary means of seed production. This contrast in breeding systems from Iowa and Illinois may result from genetic differences between populations that affect flowering structure and phenology.

Seed Production

Seeds develop in siliques 2.5 - 6 cm long by 2 mm wide on stocky pedicles 4 - 6 mm long. Seeds typically number 10 to 20 per silique depending on the number of fruits and alternate on either side of the sinus within each silique. Seeds are brown to black, 3 mm by 1 mm and can be cylindrical or ellipsoid with a transverse ridge close to the apex (Cavers et al. 1979). The number of seeds and siliques is positively correlated with plant height, and the ratio of seeds per silique reported to increase with plant height in some systems (Smith et al. 2003), although the number of siliques is the best predictor of fecundity in other studies (see Chapter 2). Susko and Lovett-Doust (1998) showed that 94% of ovules show signs of fertilization and begin development, and an average of 68% of ovules develop into mature seeds. Seed rain by *A. petiolata* has been reported at 15,000 seeds/m^2 (Anderson et al. 1996).

Fecundity can be reduced by several factors. Susko and Lovett-Doust (1998) showed that damage to 50 - 75% of the root system in second year plants decreased the number of developing fruits on plants by 8 - 13% and decreased the number of fruits reaching maturity by 4%. Damage to or removal of leaves significantly decreases fruit set. Removal of 50% and 100% of cauline leaves caused a 25% and 46% reduction in mature fruit production, respectively. However, the stems, fruits, and immature seeds of *A. petiolata* are green and are likely photosynthetic and compensate for some degree of defoliation. Significant numbers of mature seeds are still produced even when all cauline leaves are removed (Susko and Lovett-Doust 1999). Other factors that influence seed production include plant size and location of flowers within inflorescences (Susko and Lovett-Doust 2000b). Plants senesce after seed set, although *A. petiolata* in Europe perennates by the formation of adventitious buds (Cavers et al. 1979).

Response to Light Conditions

Alliaria petiolata plants reach their seasonal A_{max} (maximum photosynthetic rate) in early spring prior to canopy leaf out and emergence of competing native ground layer plants and when the solar irradiance reaching the forest floor at mid-day is greatest (Myers and Anderson 2003). Numbers of leaves and dry biomass in first year plants are positively correlated with higher light levels, lower plant densities, and with increased nutrient availability (Meekins and McCarthy 2000). Shoot biomass allocation is greatest among plants grown in higher densities under low light conditions. First year rosettes have photosynthetic rates and stomatal conduction typical of other shade-adapted plants. Under low light levels, *i.e.* plants raised under light conditions typical of a forest understory (189 ± 93 μmol m^{-2} s^{-1}), attain higher A_{max} and stomatal conduction than those grown under full sun. Under high light conditions, the plants grown under full sun had higher measured A_{max} than those grown under shade. However, while A_{max} and maximum stomatal conduction are positively correlated with the light conditions, *A. petiolata* never reaches photosynthetic rates or stomatal conduction comparable to full-sun-adapted species. Plants grown under shade have higher chlorophyll content than those grown under full sun (Dhillion and Anderson 1999, Meekins and McCarthy 2000). Myers et al. (2005) found displays of similarly plasticity in in A_{max} and stomatal conductance responses to variation in light conditions. They also found that plants grown under higher light conditions (0 and 30% shade cloth) produced greater biomass and leaf mass than those grown under lower light (60% shade cloth), but plants grown under low light had higher leaf chlorophyll *a* and *b* concentrations. Thus, while it is shade tolerant and obviously capable of growing and competing successfully under a closed forest canopy, *A. petiolata* seems optimally adapted to growing in edge habitats or canopy gaps where light levels are intermediate. Experimental removals of invasive *Lonicera maackii* (Amur honeysuckle) shrubs and *Acer platanoides* (Norway maple) canopy trees has shown that *A. petiolata* does respond positively to the formation of canopy gaps and can increase in abundance even as other principal invaders are removed (Luken et al. 1997, Webb et al. 2001).

HABITAT

Alliaria petiolata is a disturbance adapted species which profits from anthropogenic and natural disturbances (Pyle 1995, J. Evans personal observation) and can tolerate extraordinarily harsh growing conditions. In a study of the metal content of plants at a lead battery dump site where soil lead concentrations reached 140,500 mg/kg Pb, the native plant *Ambrosia artemisiifolia* had lead concentrations up to 1695 mg/kg Pb while lead was undetectable in A. *petiolata* (Pichtel et al. 2000). Work by Byers and Quinn (1987) and others (e.g. J. Evans Chapter 2) has shown that *A. petiolata* can successfully colonize and reproduce across a wide range of habitat types ranging from periodically inundated floodplain forests to dry oak-woods. Biomass of *A. petiolata* is positively correlated with soil pH in Illinois (Anderson and Kelley 1995), although survival rate is not. The effect of pH on growth may be an effect of lower inorganic nutrient availability that is typical of more acidic soils. Experiments by Meekins and McCarthy (2001) indicated that plant performance, including germination, survival, plant size and seed production, is higher in lowland forests where soil moisture is higher and leaf litter per unit area is lower compared with upland forest plots. Performance is also higher in edge plots where light availability is greater than in forest interior plots. Removal of leaf litter does not significantly affect performance of *A. petiolata*, though. However, plots with low densities of *A. petiolata* have significantly greater survival rates, plant size, and fruit production. These conditions are similar to those found in newly colonized patches and may account for *A. petiolata*'s ability to spread rapidly and dominate new areas (Meekins and McCarthy 2002).

RANGE OF *ALLIARIA PETIOLATA*

Native Range

Alliaria petiolata occurs throughout northern Europe south of 68°N from England east to Czechoslovakia and from Sweden and Germany south to Italy. (Nuzzo 1993b, 2000). It is also a constituent of the native flora in Northern India and coastal North Africa (Welk et al. 2002).

Introduced Range

Alliaria petiolata has spread from its native range in Europe to Sri Lanka, New Zealand (Bangerter 1985) and much of North America, although its occurance in Sri Lanka has not been confirmed by recent floristic writings (Nuzzo 2000, Welk et al. 2002). *Alliaria petiolata* was first reported in North America on Long Island, New York, in 1868 (Nuzzo 1993a), where it was likely introduced by immigrants from the old world. In North America *A. petiolata* is most abundant in New England and the Midwest with populations now present in at least 34 U.S. States and 4 Canadian Provinces (Nuzzo 2000) and appears to have become established near Juneau, Alaska, in 2001 (The Nature Conservancy 2002, Ellen Anderson, USDA Forest Service personal communication November, 2005).

Welk et al. (2002) have predicted the equilibrium distribution of *A. petiolata* in North America using a climate based model and give a detailed description of its temperature and precipitation requirements throughout the year. The primary core infestation matches climatic conditions with *A. petiolata*'s native range 100%. It is expected to stretch from Prince Edward Island west to Minnesota and from North Carolina through Kentucky and Illinois west to Iowa. A second core zone in the Pacific Northwest extends from southeastern Oregon northward along the Pacific coast to southwestern British Columbia and from the northern reaches of Idaho to northwestern Montana. Concentric zones of decreasing probability of infestation extend outward from core zones. *Alliaria petiolata* is still spreading though its introduced range in North America, so predictions about its future distribution are considered preliminary. Some populations of *A. petiolata* have been identified outside of the predicted core areas, in Kansas and Alaska, for instance.

Peterson et al. (2003) created an ecological niche model to make predictions about *A. petiolata*'s potential invasive range that explain its occurrence in Kansas. Using geological, hydrological, climatic, and topographic data from *A. petiolata*'s native range to calibrate the model, they predict a larger invasive range than Welk et al. (2002). Their map of *A. petiolata*'s potential range includes nearly all of the continental United States and Southern Canada exclusive of the high Rocky Mountains, almost all of Mexico, and the Caribbean islands.

Genetic Variation

Several groups have studied *A. petiolata* genetics. Meekins et al. (2001) performed analyses of genetic variation within and between three North American and eight European populations of *A. petiolata*. Analysis of genetic variance showed that variance was greatest among populations (61.0%) and that variance is substantially lower between continents (16.3%) and within individual populations (22.7%). Their findings indicate that sample populations from Ohio, West Virginia, New York, and Kentucky could possibly have originated from stock in the British Isles. Of the three native range populations sampled, those from Belgium and The Netherlands were most similar, and plants from Scotland belonged in a separate group. More recently Durka et al. (2004) isolated eight new microsatellite loci from *A. petiolata*. An inter-continental analysis using these microsatellite loci indicated lower genetic variability in the introduced range than in the native range, but diversity was high enough in the introduced range to suggest that *A. petiolata* has been introduced to North America multiple times (Durka et al. 2005). Durka et al. (2005) found no evidence of a population bottleneck and similar, low rates of heterozygosity on both continents, which is consistent with high observed rates of self-fertilization. The populations they studied from North America shared the greatest proportion of alleles with Northern and Central European and British Isles populations, which were likely sources of introduction.

INVASIVENESS OF *ALLIARIA PETIOLATA*

Alliaria petiolata is a successful invader that has demonstrated its ability to disrupt and restructure natural (e.g. Nuzzo 1993a, Meekins and McCarthy 1999, Nuzzo 1999) and urban (Yost et al. 1991) forest communities throughout its North American range. Numerous studies have attempted to dissect the nature and mechanisms of its invasiveness. *Alliaria petiolata* appears to owe its invasiveness at least in part to its cold tolerance. First, *A. petiolata* germinates and later resumes growing during its second year while temperatures are still low and before trees have leafed out and closed the forest canopy. From studies on responses to different light levels (Dhillion and Anderson 1999, Meekins and McCarthy 2000), we know that *A. petiolata* reaches its maximum photosynthetic and growth rates under conditions just short of full sun. Thus, *A. petiolata* is able to grow rapidly for several weeks before other understory plants emerge and it has an opportunity to overtop and shade them. Additionally, *A. petiolata* overwinters as a green rosette and is able to photosynthesize and grow whenever temperatures rise above freezing. A growing body of current research suggests that exotic earthworms increase litter cycling rates (Bohlen et al. 2004, Hale et al. 2005a), alter soil structure (Hale et al. 2005b) transport and store weed seeds (Smith et al. 2005) and may also be correlated with increased abundance of invasive plants (Kourtev et al. 1999) and *A. petiolata* specifically (Maerz et al. 2002, C.M. Hale, Univ. of Minnesota, Duluth, personal communications 2003). Although many negative impacts of *A. petiolata* on native communities have been surmised, few studies have shown evidence of large-scale impacts on invaded communities. Ground beetle (Coleoptera: Carabidae) assemblages, species richness and other invertebrate prey abundances show no correlation with *A. petiolata* presence or absence (Davalos and Blossey 2004). McCarthy (1997) experimentally removed *A. petiolata* from forest communities and measured subsequent changes in community composition for over two years. He concluded that diversity increased as *A. petiolata* was removed, but this is somewhat confounded and difficult to interpret because the sign of the effect he observed changed multiple times over the course of his study.

Meekins and McCarthy (1999) studied competitive interactions between *A. petiolata* and several native species in Ohio and found that both *Acer negundo* and *Impatiens capensis* are superior competitors to it but that *Quercus prinus* seedlings were less successful competitors than *A. petiolata*. This implies that some oak forests may be at risk of reduced regeneration rates through seedling suppression by *A. petiolata*.

Better Living through Chemistry

In coevolved communities, natural selection is expected to favor organisms with mechanisms of reducing competitors' fitness and competitive ability, while at the same time competitors should be selected for their ability to tolerate those offenses. In plant communities these interactions can be mediated through the production of secondary chemical compounds. The Novel Weapons Hypothesis (Callaway and Ridenour 2004) posits that when plants invade communities with which they share little recent evolutionary history, the invaded community is not likely equipped to tolerate the invaders' chemistry. Similarly, naïve insect herbivores whose life cycles are closely tied to relatives of an invading plant may be chemically attracted to the invader, but other chemistry or plant properties render it unacceptable as a host, and it will serve as a population sink if larvae cannot develop on it. Both of these phenomena have been shown to occur where *A. petiolata* invades certain North American communities.

Allelopathy: Interactions with Plants

Numerous studies have found *A. petiolata* to be chemically well equipped for both defensive and potentially offensive purposes which may contribute to its invasiveness via several mechanisms. Allelopathy has a been cited as a cause of increased invasive ability in several invasive plants including knapweeds (*Centaurea spp.*, *Acroptilon repens* (L.)) (Bais et al. 2003, Grant et al. 2003, Weston and Duke 2003) and

Tree-of Heaven (*Ailanthus altissima* (Miller)) (Call and Nilsen 2003). McCarthy and Hanson (1998) applied root and shoot extracts of *A. petiolata* to seeds of four target species: radish, winter rye, hairy vetch, and lettuce. Radish germination rate and shoot biomass of rye were depressed by treatment with the extracts, but the authors concluded that allelopathy is unlikely to be important in *A. petiolata*'s invasion ecology.

Vaughn and Berhow (1999) criticized McCarthy and Hanson's methods and pointed out that several highly phytotoxic products of glucosinolate hydrolysis are not extractable as prepared. More specifically, the chemicals allyl isothiocyanate (AITC) and benzyl isothiocyanate (BzITC), which result from the breakdown of their less toxic parent compounds sinigrin and glucotropaeolin, are almost entirely insoluble in water. The aqueous preparations used by McCarthy and Hanson (1998) would not likely have contained these important toxins and would not be expected to affect the growth of other plants. Dichloromethane extracts of *A. petiolata* tissues prepared by Vaughn and Berhow contained both AITC and BzITC as well as 2,3-epithiopropylnitrile. Solutions of AITC and BzITC and their parent compounds were lethal to cress (*Lepidium sativum* L.) and wheat (*Triticum aestivum* L.) although the isothiocyanates were lethal at concentrations an order of magnitude more dilute than their parent glucosinolates. Concentrations of these compounds vary seasonally in natural *A. petiolata* populations. Sinigrin and glucotropaeolin are undetectable in spring-harvested leaves and stems but are present autumn-collected specimens. Sinigrin is present in roots at similar concentrations in both spring and fall, but root-concentrations of glucotropaeolin are over three times as great in fall than in spring (Vaughn and Berhow 1999).

Work by Prati and Bossdorf (2004) has demonstrated the allelopathic ability of *A. petiolata* by other means. They showed that germination rates of a North American native plant were reduced in soils in which *A. petiolata* had been grown compared with control soils and that germination of congeneric European plants was positively affected by *A. petiolata* treated soils. Allelopathic effects of *A. petiolata* specimens collected in North America were grater than those of European specimens in concordance with Blossey and Nõtzold's (1995) Evolution of Increased Competitive Ability hypothesis (EICA). However, Prati and Bossdorf only measured allelopathic affects on one European and one North American species. Further field trials involving greater species numbers should be undertaken to increase confidence in their results.

Vaughn and Berhow (1999) demonstrated direct allelopathy by compounds present in *A. petiolata*, but they also point out that the glucosinolates and glucosinolate derivatives in their and other studies inhibit growth of mycorrhizal fungi. They propose that this could enable a mechanism for competitive superiority of *A. petiolata* over many native plants that are dependent on arbuscular mycorrhizal fungi (AMF). Subsequent experiments have explored this hypothesis. Aqueous leachates of whole *A. petiolata* plants prevented germination of spores of the AMF *Gigaspora rosea,* reduced germination rates of tomato seeds, and prevented association of tomato seeds with AMF (Roberts and Anderson 2001). In natural communities, Roberts and Anderson (2001) also identified a negative correlation between local *A. petiolata* density and soil mycorrhizal inoculum potential which they suggest could negatively impact native plants that are dependent on AMF associations. This has been verified in other systems where the persistence of anti-mycorrhizal compounds in the soil prevented re-inoculation with AMF for years after *A. petiolata* removal (Stinson and Klironomos 2005). This study showed that later successional plants, which are more highly dependent than early successional plants on AMF associations, are negatively affected by *A. petiolata* and suffer from reduced growth and regeneration in its presence. Interactions of this kind have the potential to radically alter forest regeneration and successional trajectories. Stinson et al. (2005) experimentally demonstrated negative relationships between *A. petiolata* abundance and native species diversity and cover. These community responses could be mediated through competition, direct allelopathy, AMF suppression by *A. petiolata*, or a combination of mechanisms. Prati, Klironomos, Calloway and others are carrying out additional studies on *A. petiolata* allelopathy and plant-soil feedback mechanisms (R. Calloway, U. of Montana, personal communication January 22, 2004). In McCarthy's removal study (1997) it seems likely that although *A. petiolata* was removed from his experimental plots, his results may have been influenced by the lasting suppression of soil AMF by *A. petiolata* secondary chemicals as others have shown.

Defensive Chemistry: Interactions with Insects

In North America *A. petiolata* is utilized as a nectar source by the spring azure butterfly *Celastrina ladon* (Yahner 1998) and is accepted as a host for oviposition by the native butterfly *Pieris napi oleracea* P. (Lepidoptera: Pieridae) (Porter 1994b). However, *P. n. oleracea* is unable to complete development on *A. petiolata* with most larvae dying in the first or second instar (Porter 1994b). First instar larvae are deterred from feeding by the presence of the cyanoallyl glycoside alliarinoside ((2*Z*)-4-(*β*-D-glucopyranosyloxy)-2-butenenitrile) (Haribal and Renwick 2001, Haribal et al. 2001, Renwick et al. 2001) while fourth instar larvae are deterred by the apigenin derivative isovitexin-6"-D-β–glucopyranoside (Haribal and Renwick 1998, Haribal et al. 1999, Renwick et al. 2001). Concentrations of these secondary chemicals vary temporally with levels near zero in June and July, which may explain why larval development and survival rates on *A. petiolata* vary (Haribal and Renwick 2001). Larvae of the congeneric butterfly *P. rapae* are stimulated to feed by extracts of glucosinolates from *A. petiolata* and other Brassicaceaeous plants (Renwick and Lopez 1999). Renwick (2002) postulates that a similar attraction leads *P. n. oleracae* to oviposit on *A. petiolata*, even though other plant secondary chemicals inhibit larval development. *Alliaria petiolata* thereby serves as a population sink for this native butterfly through a series of chemical "lures" and "traps" (Renwick 2002). Porter (1994a) observed *P.n. oleraceae*'s uncommon congener *P. virginiensis* ovipositing on *A. petiolata*. Where *P. virginiensis's* primary hosts, *Dentaria* spp. (Brassicaceae) are rare and *A. petiolata* is abundant, *A. petiolata* is a preferred host, despite its unpalatability. If eggs are preferentially laid on unacceptable host plants, it is possible that this species' abundance will decline though a similar population sink mechanism.

Interactions with White-Tailed Deer

White tailed deer (*Odocoileus virginianus*) (Boddaert) are important herbivores in the fragmented agricultural landscapes of the Midwestern United States. Deer browse can significantly alter the species composition of forest understory communities (Rooney 2001) and may disproportionately affect Liliaceae in some areas (Augustine 1997). Estimates of deer densities in North America prior to European settlement ranged from 2 – 4.2 deer km^{-2} (Alverson et al. 1988, Rooney 2001) while current deer densities in

Michigan are as high as 28.6 deer km^2 (MDNR 2006 Montcalm County). Kalisz et al. (2003) found that trampling and selective browsing of native vegetation by deer facilitated invasions by *A. petiolata*, but native species increased in abundance in areas from which deer were excluded and were more competitive with *A. petiolata*. In particular, the native species *Trillium grandiflorum* (Liliaceae) appeared to benefit from protection from browsing while *A. petiolata* became less successful at establishing and reproducing. Based on these findings a study evaluating the individual and combined impacts of deer and *A. petiolata* on native plant communities was established in southern Michigan and is ongoing (J. Evans unpublished).

Differences between European and North American *Alliaria petiolata* populations

Blossey and Nötzold's (1995) Evolution of Increased Competitive Ability (EICA) hypothesis proposed that in the absence of natural enemies, selection should favor individual plants with increased resource allocation to growth and decreased allocation to energetically expensive defenses. Bossdorf et al. (2005) reviewed papers that address various components of the EICA hypothesis in many invasive plant species. Of the studies that tested components of EICA on *A. petiolata,* nearly all either indicate zero differences between native (European) and introduced (North American) populations or they fail to support EICA. The only exceptions were Prati and Bossdorf's (2004) previously described allelopathy study and a study in which feeding rates of the European specialist herbivore *Ceutorhynchus scrobicollis* (Coleoptera: Curculionidae) were greater on introduced than on native *A. petiolata* populations (Bossdorf et al. 2004). This indicates that *A. petiolata* in North America may have lost some ability to defend itself against specialist herbivores and thus may be vulnerable to them if they are introduced as biocontrol agents. However, the remaining body of work reviewed suggests that introduced *A. petiolata* has not traded off defenses for an increase in competitive ability. Rather, it shows that the introduced populations are equally or less competitive than European ones (Bossdorf et al. 2005) and are at least as well chemically defended as well (Cipollini 2002, Cipollini et al. 2005). These findings may have important implications for developing efforts to control *A. petiolata* invasions in North America.

MANAGEMENT OF INVASIVE GARLIC MUSTARD

Resource managers in North America perceive expanding *A. petiolata* populations as threatening to many of their specific goals including conservation, recreation, and wildlife management. Efforts to control or reverse the spread of *A. petiolata* both locally and nationally have taken myriad approaches and are currently still being developed.

CONVENTIONAL CONTROLS

A number of conventional techniques have been developed in attempts to control *A. petiolata*, including prescribed fire, chemical and mechanical controls. These methods have proven insufficient in all but the smallest infestations. Additionally, treatments must be repeated annually or semi-annually until the seed bank is exhausted to prevent re-establishment after treatment.

Prescribed Fire

Several groups have explored the use of prescribed burning to control *A. petiolata* and produced mixed results. Luken and Shea (2000) found no significant effect of burning on *A. petiolata* populations after three consecutive years of treatment in Kentucky. Mid intensity fires (flames ~15 cm high) in late spring that completely burn an area can effectively reduce *A.* petiolata populations (Nuzzo 1991). However, fires often burn patchily and do not eliminate all target vegetation, requiring further mechanical or chemical treatment of remaining plants. Fall conditions in Nuzzo's (1991) Illinois trials were frequently too wet to produce a thorough burn, and low intensity fires (flames up to 3 cm) have no impact on *A. petiolata* populations.

Nuzzo et al. (1996) set repeated, controlled hot fires (flames >1 m) during three consecutive springs and in alternate autumns and springs over four years. All plots were free of *A. petiolata* following fire treatments but were quickly reinfested when treatment was discontinued. Herb coverage increased 65 - 66% and species richness increased 50% after two consecutive burns, although woody cover was not significantly affected. Spring and autumn high-intensity fires had equal effects on *A. petiolata* (Nuzzo et al. 1996, Schwartz and Heim 1996), although Nuzzo (2000) points out that spring fires should be most effective in reducing *A. petiolata* coverage because they affect both the newly emerged seedlings and the rosette stage from the previous season's cohort. Fires that do not completely remove the litter layer may actually increase *A. petiolata* coverage by promoting growth of new flowering stems from axillary buds (Nuzzo et al. 1996). Prescribed burning may be effective in controlling mid-sized *A. petiolata* populations if used repeatedly and in combination with other methods. Fire is only recommended for fire-adapted communities and may produce undesirable effects if used inappropriately.

Chemical Control

A number of herbicides have been explored for *A. petiolata*, including glyphosate (Nuzzo 1991, 1996), 2,4-D (Rich Dunbar personal communication 1990 in Nuzzo 2000; Nuzzo unpublished in Nuzzo 2000), 2,4-D plus Dicamba (Bill McClain personal communication in Nuzzo 2000), Kilmor (a 2,4-D formulation) (R.H. Brown personal communication 1977 in Cavers et al. 1979), triclopyr (Rich Dunbar personal communication 1990 in Nuzzo 2000), bentazon and acifluoren (Nuzzo 1994, 1996). 2,4-D is not indicated for use on *A. petiolata*, although a 2,4-D ester formulation reduced *A. petiolata* cover up to 70% when applied at 0.09 kg/ha during the growing season (Nuzzo 2000). Likewise, acifluoren is not recommended (Nuzzo 2000). While triclopyr, 2,4-D plus Dicamba, and Kilmore have been used in limited trials, insufficient testing has been conducted to recommend these products. More extensive data on glyphosate and bentazon are available.

Dormant season broadcast (overspray) application of 1%, 2%, and 3% glyphosate in late autumn or early spring reduced *A. petiolata* cover by over 95% without significant impact on other herbaceous species, although sedge cover was reduced by >83% (Nuzzo 1991, 1996). Carlson and Gorchov (2004) spot applied 1% glyphosate to *A. petiolata* in late autumn in an old growth *Acer-Fagus* forest and a second growth *Liriodendron* forest and found similar reductions in *A. petiolata* in subsequent years and observed increase cover of native spring ephemerals and increased reproduction of the native perennial *Phryma leptostachya* (lopseed). They concluded that targeted treatment of *A. petiolata* can positively impact native communities, but their methods are labor intensive and may not be feasible for application at large spatial scales.

Application of bentazon (Basagran) at 0.09-0.18 kg/ha reduced coverage of rosettes 90-95% (Nuzzo 1994), although dormant season application effects are unknown (Nuzzo 1996). Bentazon is highly soluble in water has a low affinity for soil particles, which creates the potential for groundwater contamination (Nuzzo 2000). This must be weighed against its lower toxicity to non-target sedges and grasses.

Cutting

Cutting *A. petiolata* stems has been used with mixed success to control small infestations. Nuzzo (1991) found that stems cut at ground level and at 10 cm showed 99% and 71% mortality, respectively, compared with a natural mortality rate of 6% in control plots. Seed production was reduced 100% and 98% respectively in plants cut at ground level and at 10 cm above ground level. Plants cut during the height of bloom with developing siliques have the least stored resources and are least likely to produce new stems and recover from cutting (Nuzzo 2000).

Viable seeds can develop on cut stems (Solis 1998). In his experiment, Solis pulled *A. petiolata* stems in successive stages of development (budding plants, blooming plants, early silique, and late siliques with developing seeds) and laid them to overwinter in mesh-enclosed plots. The following spring *A. petiolata* seedlings had germinated in all but his control plots, implying that seeds had developed to maturity on the pulled stems. Solis recommends removing and destroying all pulled stems from the site to prevent further seed set. As an extension of this, Nuzzo (2000) recommends removing and destroying cut stems as well. Stems can be cut with a weed whip, although care must be taken to avoid damaging non-target species and to prevent spreading the cut stems, as stated above (Nuzzo 2000).

Pulling

Pulling is an effective control technique in very small infestations (Nuzzo 2000). When pulling plants, it is important to remove the upper portion of the roots as well as the stem, since buds in the root crown can produce additional stems (Nuzzo 2000). All pulled plants should be removed from the site as seed ripening continues even after plants are pulled (Solis 1998). Repeatedly hand pulling of garlic mustard is reported to be effective for control in small areas but has limitations. Because seeds remain viable in the soil for up to five years, it is important to pull all garlic mustard plants in an area every year until the seed bank is exhausted and seedlings no longer appear. This will require multiple efforts each year as rosettes can continue to bolt and produce flowers over an extended period (April-June). Pulling is advantageous over cutting in that it can be done at any time during *A. petiolata's* lifecycle before seeds dehisce. Cutting the roots is effective as well, although it is labor intensive (Nuzzo 2000).

Mowing

Mowing as a control method should be approached with caution (Nuzzo 2000). Mowing equipment may not be appropriate for use in sensitive areas as it is likely to disturb the soil and damage desirable plants as well as *A. petiolata*. Nuzzo (2000) suggests that while mowing appears to be an attractive option for areas like roadsides, it could serve to spread seeds within and between sites if seeds are not removed from equipment.

Other

Draining, dredging, and grazing have not been tested (Nuzzo 2000), although cattle reportedly do feed on *A. petiolata* (Cavers et al. 1979). Midsummer flooding is capable of killing rosettes, but floodwaters apparently accelerate the invasion process by spreading *A. petiolata* seeds (Nuzzo 1999). Nuzzo (2000) suggests that disking is inappropriate for *A. petiolata* as the soil disturbance it creates damages desirable plants.

BIOLOGICAL CONTROL

Many conventional methods described above have been explored to control *Alliaria petiolata*. However, *A. petiolata*'s high seed production, persistent seed bank, and tolerance for varied light conditions render it difficult to control, and land managers are unable to successfully curb its spread. More powerful management tools are necessary to reverse the trajectory of *A. petiolata*'s population growth. In April, 1998 a search for appropriate biological control organisms was launched to address this need (Hinz and Gerber 1998). This effort is being carried out by CABI Bioscience in Switzerland and at the University of Minnesota. It is funded by the USDA Forest Service through Cornell University and the Minnesota Department of Natural Resources. Blossey et al. (2001b) and Hinz and Gerber (2005) have summarized the search for biocontrol agents. More complete information is found in CABI's annual project reports (Hinz and Gerber 1998, 2000, 2001, Gerber et al. 2002, Gerber et al. 2003, Gerber et al. 2004, 2005).

An initial survey of the literature by Hinz and Gerber (1998) found 69 species of phytophagous insects and 17 fungi in Europe that are associated with *A. petiolata*. Of these, 28 insect species were collected in Switzerland, Germany and Austria in 1998 and 1999, and 20 were reared (Hinz and Gerber 1998, 2000). Six species were identified as potential biological controls and five have been subjected to further testing. Four species belonging to the subfamily Ceutorhynchinae (Coleoptera: Curculionidae) are in the genus *Ceutorhynchus*. These are: *C. alliariae*, *C. roberti*, *C. constrictus*, and *C. scrobicollis*. A fifth *Ceutorhynchus* species, *C. theonae*, was studied in 2000 and 2001 but was difficult to collect and rear and was thereafter discontinued (Gerber et al. 2003). *Phyllotreta ochripes* (Curtis) (Coleoptera: Chrysomelidae) has also been tested. The sixth species, *Ophiomyia alliariae* Hering (Diptera: Agromyzidae), was not found during initial or subsequent surveys and has not been tested as a potential control agent.

Potential Agent: *Phyllotreta ochripes*

Phyllotreta ochripes (Curtis) (Coleoptera: Chrysomelidae) larvae feed beneath the epidermis on roots or root crowns of *Alliaria petiolata* rosettes and bolting adults (Hinz and Gerber 1998, Blossey et al. 2001b). Tests for host specificity of this flea beetle were conducted in 1999 and 2000 (Hinz and Gerber 2000, 2001) and were confirmed by multiple choice tests in 2001 (Gerber et al. 2002). Results showed that *P. ochripes* is capable of completing development on a number of Brassicaceae including *Brassica* spp. and *Rorippa* spp.. In 2001 *P. ochripes* was determined to be to oligophagous to be released in North America and further testing was suspended (Gerber et al. 2002).

Potential Agents: *Ceutorhynchus alliariae* and *C. roberti*

Ceutorhynchus alliariae Bristout and *C. roberti* Gyllenhal (Coleoptera: Curculionidae) share similar life histories (Blossey et al. 2001b, Gerber et al. 2002). Larvae mine in stems and leaf petioles from March to May and pupate in the soil. Adults emerge later the same summer and feed on leaves of *A. petiolata*. Adults overwinter in the litter and soil, emerge early in the spring and soon begin ovipositing. Eggs of *C. alliariae* are laid individually while those of *C. roberti* are laid in groups of up to nine in *A. petiolata* stems and leaf petioles. Development takes from 1-3 weeks. Larvae hatch and feed in stems and leaf petioles for approximately 7 weeks before third instar larvae enter the soil to pupate. Adults emerge in June and feed on leaves. The adults of *C. alliariae* are capable of flights of at least 1 km, although *C. roberti* adults have only been observed flying short distances and infrequently (Gerber et al. 2004). Both species are univoltine and can be distinguished from one another as adults by tarsal coloration, although larvae are indistinguishable (Blossey et al. 2001b). Both can also survive for more than two years and have a third oviposition season (Gerber et al. 2003).

In host specificity testing *C. roberti* has accepted 11 of 40 host species for oviposition that were offered in sequential no-choice tests, and *C. alliariae* accepted 23 of 63 species - all within the family Brassicaceae. In single choice oviposition tests *C. roberti* accepted 10 of 18 host plants offered and *C. alliariae* accepted 12 of 23. During no choice development trials, *C. roberti* completed development on three of 22 host species offered (*Rorippa nasturtium-aquaticum* (= *Nasturtium officinalis*), *Thlaspi arvense*, and *Peltaria alliacea* - all Brassicaceae) and *C. alliariae* developed successfully on two of 19 species offered (*R. nasturtium-aquaticum* and *Thlaspi arvense*) (Hinz and

Gerber 2005). Further host specificity testing of *C. roberti* and *C. alliariae* is being continued at the University of Minnesota's quarantine laboratory in St. Paul on several additional North American plant species (Katovich et al. 2005). Both *C. alliariae* and *C. roberti* are still currently considered candidate agents (Gerber et al. 2004, Gerber and Hinz 2005, Gerber et al. 2005).

Potential Agent: *Ceutorhynchus constrictus*

Ceutorhynchus constrictus (Marsham) (Coleoptera: Curculionidae) has the narrowest host range of the candidate biocontrol agents to date (Hinz and Gerber 2005). Larvae feed on seeds from May to July and then leave the host plant to pupate in the soil. Adults emerge the following April to feed on leaves and mate. Females in fecundity trials laid an average of 164 eggs from 21 May to 21 June (Hinz and Gerber 2000). Eggs hatch after 15 to 20 days, and larvae exit seeds to pupate in the soil from 28 to 44 days later. Each larva destroys 2.5 ± 0.34 seeds on average (Gerber et al. 2002).

Of 54 host plant species offered in no choice oviposition trials, *C. constrictus* females accepted ten in the genera *Arabis*, *Aurinia*, *Brassica*, *Barbarea*, *Rorippa*, and *Cardamine* (all Brassicaceae) (Gerber et al. 2004, 2005). Of these ten species only one (*Barbarea vulgaris*) was accepted in single choice trials implying *C. constrictus*'s preference for *A. petiolata* (Gerber et al. 2002, Gerber et al. 2004, 2005). *Brassica nigra* alone supported development of *C. constrictus* to the adult stage in no-choice development trials, but this species was not attacked in open-field trials in 2003 which suggests that it is not likely a normal field host of this insect. Additionally, *C. constrictus* is not a known pest on commercially produced *B. nigra* in Europe (Gerber and Hinz

2005, Hinz and Gerber 2005). *Ceutorhynchus constrictus* is the most common European species of *A. petiolata* feeders in its genus. However, attack rates by *C. constrictus* on *A. petiolata* in the field are typically low, reducing seed production by 0.3 - 6.4% in Switzerland and southern Germany (Blossey et al. 2001b).

Potential Agent: *Ceutorhynchus theonae*

Ceutorhynchus theonae Korotyaev & Cholokava (Coleoptera: Curculionidae) is the most recently identified potential biocontrol agent for *A. petiolata*. It was first collected in Daghestan, Russia, in early 2000 and was reared in quarantine by CABI in Switzerland through 2001 (Blossey et al. 2001b, Gerber et al. 2002). Larvae feed on seeds of *A. petiolata* (Blossey et al. 2001b), although little else has been published on its biology. Work on *C. theonae* was suspended after the 2001 field season because of collection and rearing difficulties (Gerber et al. 2003).

Potential Agent: *Ceutorhynchus scrobicollis*

Ceutorhynchus scrobicollis Nerensheimer & Wagner (Coleoptera: Curculionidae) larvae feed in leaf petioles, buds, and root crowns of overwintering *A. petiolata* rosettes. Larvae leave the plants to pupate in the soil by late April. Adults emerge from May to June and aestivate during summer. Females begin laying eggs in mid September and oviposit continually through winter into spring. Individual females can produce viable eggs for at least three consecutive years, although few survive that long and fecundity decreases with age. This may still have positive implications for establishment and spread if this species is released (Gerber et al. 2002, Gerber et al. 2003, Gerber et al. 2004).

Ceutorhynchus scrobicollis was not found during initial collecting trips in Switzerland and southern Germany in 1998, although it was collected Germany in subsequent years (Hinz and Gerber 2000, 2001, Gerber et al. 2002, Gerber et al. 2004, 2005).

Ceutorhynchus scrobicollis oviposited on 35 of 73 host plant species offered in sequential no-choice tests. Of these, six in the Brassicaceae and three in other families are native to North America. These include *Hydrophyllum virginianum* (Hydrophyllaceae), *Viola sororia* (Violaceae), and *Phlox divaricata* (Polemoniaceae). Eggs were laid on the surface of *H. virginicum*, *V. sororia*, and *P. divaricata* and desiccated prior to larval emergence, whereas they are normally deposited in leaf petioles. The authors of these studies raise doubts as to whether *C. scrobicollis* would complete development under these conditions (Gerber et al. 2005, Hinz and Gerber 2005). All three non-Brassica North American species co-occur with *A. petiolata* in Michigan at one or more *A. petiolata* study sites (Evans unpublished data, and see Chapter 3). Three North American species (*Draba sp.*, *Cakile edentulata*, and *Lepidium virginianum*, - all Brassicaceae) and eight other species (all Brassicaceae) were accepted for oviposition during single-choice oviposition tests in 2002 (Gerber et al. 2003). In larval development trials *C. scrobicollis* adults emerged from five of 37 species offered. These included the three species that *C. roberti* and *C. alliariae* accepted in similar trials (*R. nasturtium-aquaticum*, *P. alliacea*, and *T. arvense*) (Gerber et al. 2005). Experiments comparing *C. scrobicollis*'s feeding behavior indicate that it prefers *A. petiolata* plants grown from North American seed over European plants (Bossdorf et al. 2004). This implies that estimates of *C. scrobicollis* feeding and infestation rates made on European *A. petiolata* may be low for North America.

Interactions Between Potential Biocontrol Agents

Experiments conducted in 2000 and 2001 revealed strong but symmetrical intra- and interspecific competitive interactions between *C. alliarae* and *C. roberti* (Gerber and Hinz 2005). These studies showed that weevil fecundity and oviposition declined as weevil density on *A. petiolata* increased (Gerber et al. 2002). Similarly, *A. petiolata* mean height decreased linearly as the number of weevil pairs per plant increased (Hinz and Gerber 2001). However, plant responses were not species-specific and appear to be a function of weevil density alone, irrespective of species composition. The authors state that *C. alliarae* had a greater impact on plant performance than *C. roberti*, but they attribute this to *C. roberti*'s greater sensitivity to handling by experimenters and not to higher damage rates by *C. alliarae*. Although mean *A. petiolata* height was negatively impacted by feeding damage, the number of inflorescences per plant responded positively to feeding as laterally buds were released from suppression. Wilting is induced at larval densities of 20-30/shoot, although seed production is reduced at lower levels (Blossey et al. 2001b).

CABI researchers conducted experiments to identify interactions between *C. scrobicollis* and *C. alliariae,* which are temporally and spatially segregated on *A. petiolata* (Gerber et al. 2003, Gerber and Hinz 2005). They were surprised to find that, while *C. scrobicollis*-damaged plants exhibited increased mortality, a 60% reduction in biomass and a 48% reduction in fecundity compared with control plants, *C. alliariae* was not negatively impacted by the presence or abundance of *C. scrobicollis*. These effects and interactions were studied on both large and small *A. petiolata* rosettes. Larger rosettes were better able to compensate for feeding damage than smaller rosettes by producing multiple stems when attacked by one or both species, although *C. scrobicollis* had a greater impact than *C. alliariae*. In contrast, the presence or abundance of *C. alliariae* had no impact on *A. petiolata* mortality. Plants infested with *C. alliariae* alone did have significantly lower shoot heights, produced greater numbers of inflorescences than uninfested plants and produced numerically but not statistically lower numbers of seeds. The terms for interactions between the two weevil species were insignificant in their analysis. Data from available reports may be insufficient or inappropriate as reliable estimates of these insects' impacts on *A. petiolata* demographic rates in natural communities.

Biological Control Summary and Outlook

Ceutorhynchus scrobicollis and *C. alliariae* are currently the furthest along in host specificity testing. Of these *C. scrobicollis* has had the greatest impacts on *A. petiolata* performance and is predicted to be the most effective of the four weevils if released. Both of these two as well as *C. roberti* have been imported into the United States to the quarantine facility at the University of Minnesota since 2003 for further host-range testing on native North American plant species (Gerber et al. 2004, 2005, Katovich et al. 2005). While work with *C. scrobicollis* has progressed in quarantine in Minnesota, no tests have been conducted using *C. alliariae* or *C. roberti* because of difficulties encountered in getting them to lay eggs (L.C. Skinner personal communication 01/23/2006).

Of the plant species most frequently and commonly accepted for oviposition, feeding, and development by the group of potential biocontrol agents, *T. arvense* and *P. alliacea* are both native to Europe and considered by some to be invasive in North

America. Various sources list *R. nasturtium-aquaticum* in North America as either native (USDA-NRCS 2006) or exotic (Gerber et al. 2004 and references therein). The assertion that *C. roberti* and *C. alliariae* are unlikely to encounter these species under natural field conditions is plausible for *T. arvense* and *P. alliaciea*, but *A. petiolata* and *Rorippa spp.* are sympatric at one known location in Michigan where *A. petiolata* is being studied (J. Evans personal observation). The consistent acceptance of *Rorippa spp.* by multiple *Ceutorhynchus* species in host-specificity trials is of concern to some, but no conclusions have been reached yet regarding the potential for future agent releases to impact these plant species in natural communities and whether those risks are acceptable (L.C. Skinner personal communication 01/23/2006).

Petitions must be submitted to and approved by the USDA Technical Advisory Group (TAG) on weed biological control before any proposed biological control agent can be released in the United States. No petition for approval to release any of the potential agents in North America has been submitted yet, although a proposal to release *C. scrobicollis* seems a likely next step in the *A. petiolata* biocontrol program followed by proposals for the leaf miners (*C. alliariae* and *C. roberti*) and finally the seed feeder (*C. constrictus*) (Gerber and Hinz 2005). Gerber and Hinz (2005) have indicated that the first three are predicted to be compatible with each other and could potentially be released together. However, Hinz and Gerber (2005) propose that further testing of native North American *Thlaspi* and *Rorippa* species and investigation of the phylogenetic relationship of *T. arvense*, *R. nasturtium-aquaticum*, and *P. alliacea* be conducted prior to submission of a release proposal to the USDA TAG as these questions are likely to be raised by any review board.

If agents are approved, the first releases will be conducted by members of the Cornell based consortium. A similar group of state and federal collaborators carried out the highly effective purple loosestrife biocontrol program across North America (Katovich et al. 1999, Blossey et al. 2001a, Blossey et al. 2001c, Katovich et al. 2001, Albright et al. 2004) and in Michigan (Kaufman and Landis 2000, Blossey et al. 2001a, Sebolt and Landis 2002, Landis et al. 2003). Biocontrol agents for *A. petiolata* would be made available to states with a demonstrated need, baseline *A. petiolata* population data and the capability to execute successful biocontrol projects (Landis et al. 2004).

Predicting Biocontrol Requirements and Outcomes

A number of empirical and simulation studies have attempted to identify vulnerabilities in *A. petiolata* populations that can be exploited by managers. Drayton and Primack (1999) showed that extirpation of small populations can be achieved more readily than in larger poulations. Realistically, what these authors referred to as large or small "populations" were really isolated satellite patches of *A. petiolata* that ranged in size up to ~ 2000 individuals. At the scale of a site (i.e. a forest) 2000 individuals can occupy an area as small as several meters. Therefore, their findings imply that the only hope of driving local populations extinct is by managing them as soon as they are established. Their matrix population model of the *A. petiolata* lifecycle predicted that the interfering with the transition from seeds to rosettes should have the greatest impact on population growth. Rejmanek (2000) pointed out an error in their model. Preliminary results of subsequent modeling efforts predict that the rosette to flowering transition and any transitions affecting fecundity should have the greatest impact on population growth, and that these life stages would be the most fruitful targets (Davis et al. 2005, Davis et al. *in review*).

RESEARCH GOAL AND OBJECTIVES

Land managers in Michigan have identified controlling the spread of *A. petiolata* populations as a priority. When initial efforts to control *A. petiolata* by conventional means failed, managers and researchers in the state turned their attention to the development of biological control strategies. The release of natural enemy insects into novel environments has a number of associated risks that include both direct (e.g. Stiling et al. 2004, Louda et al. 2005) and indirect (e.g. Pearson and Callaway 2003, Ortega et al. 2004, Pearson and Callaway 2005) effects on non-target species or communities. These can be difficult or impossible to predict using current biocontrol agent screening standards. Researchers hope to introduce better predictive tools to the biocontrol agent screening process in the future, but these are still under development (Davis et al. 2005, Davis et al. *in review*). Prior to accepting the unknown risks of introducing natural enemies, resource managers want to know whether the spread of the invader warrants such risk. Specifically, they want to know whether invasions by *A. petiolata* are negatively impacting Michigan natural communities and whether or not existing assemblages of herbivores, pathogens, or other processes that are present in Michigan currently are controlling *A. petiolata*. If biocontrol agents are approved and released in Michigan in the future, baseline data on the invaded communities where releases will be made are necessary to evaluate the relative effectiveness and success of the biocontrol agents once established (Blossey 1999).

The overall goal of my research was to explore and interpret the biology and invasion ecology of *A. petiolata* in Michigan in support of current and future efforts to control its spread. To meet this goal, my specific research objectives were to (1) document, describe, and characterize the natural communities that *A. petiolata* invades in Michigan to allow future evaluation of potential biological control efforts, (2) determine whether populations of *A. petiolata* are spreading in Michigan, (3) evaluate the impacts of existing Michigan herbivore communities and diseases on the spread of *A. petiolata*, and (4) evaluate the interactions between *A. petiolata* and native plant communities to identify negative impacts of *A. petiolata* invasion and the response of *A. petiolata* populations to native Michigan communities.

I have addressed these core research goals in work conducted from 2003 - 2005 in southern Michigan.

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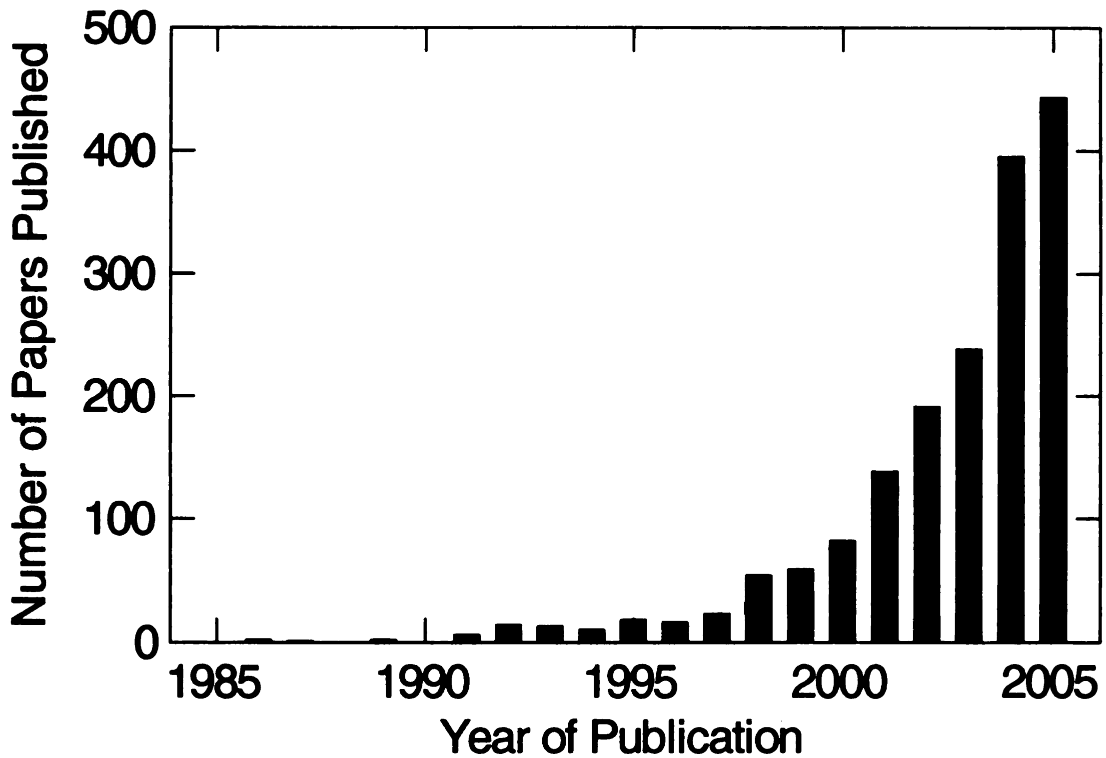

Figure 1. Results of an ISI Web of Science query using the search terms "invasive species OR biotic invasion OR biological invasion". Search performed on January 24, 2006.

Chapter 2

PRE-RELEASE MONITORING OF *ALLIARIA PETIOLATA* [GARLIC MUSTARD (M. BIEB) CAVARA AND GRANDE] INVASIONS AND IMPACTS OF EXTANT NATURAL ENEMIES IN SOUTHERN MICHIGAN FORESTS

Jeffrey Adam Evans

ABSTRACT

When conventional controls strategies fail, managers of invasive species may consider classical biological control approaches as potentially safe, cost effective, and long-term solutions. To justify releasing natural enemies and to broadly improve the rigor and safety of biological control, some authors have called for monitoring target species' populations prior to releasing natural enemies. The data collected through such activities permit evaluation of the invader's impacts on native communities and create a reference point for evaluating the effectiveness of biocontrol agents if they are later released. I collected baseline data on populations of the invasive weed *Alliaria petiolata* (garlic mustard) across its range in southern Michigan in advance of a classical biological control program. *Alliaria petiolata* populations were shown to be expanding at all sites studied with 59% of initially uninvaded sampling quadrats becoming invaded after two years. 84.5% of the quadrats with *A. petiolata* showed evidence of herbivore browsing or other damage. However, damage estimates were very low (2.9% of leaf area damaged) and were not correlated with rosette or seedling survival or with fecundity. The data presented here paint a portrait of an invasive weed that is spreading rapidly into new habitats and is unchecked by extant natural enemies. Given the rapid expansion of *A. petiolata* and the lack of significant herbivores, increasing herbivore damage with introduced natural enemies may present a new opportunity to slow or reverse the spread of this invasive plant. If natural enemy agents are released in the future, these data will provide a critical benchmark for evaluating their performance.

INTRODUCTION

The widespread ecological (Wilcove et al. 1998) and economic (U.S. Congress 1993, Pimentel et al. 2000) impacts of invasive species on both natural and managed systems have lead many managers to prioritize control of non-indigenous species. As many as 5000 non-indigenous plant species are naturalized in the United States (Pimentel et al. 2000) and present a set of unique management challenges and opportunities. Conventional control methods, such as herbicide spraying and mechanical removal, are not practical or effective on some target weeds. Practitioners of classical weed biological control consider introductions of natural enemies to be an environmentally safe and potentially effective management option. However, the rigor and safety of classical biological control as currently practiced have been challenged by some authors (Simberloff and Stiling 1996, McEvoy and Coombs 1999, Louda et al. 2003a, Louda et al. 2003b, e.g. Louda et al. 2005, Pearson and Callaway 2005).

Often cited as problematic are the limited abilities of biological control practitioners to justify implementing biological control programs for specific targets and to evaluate the relative success of programs once established. This stems in part from a historical lack of sufficient pre-release data collection as well as from a lack of post-release follow-up monitoring (Blossey 1999). Blossey (1999) addresses these concerns and points out that, for many invasive weed biocontrol programs, the evidence provided to justify the release of new biocontrol agents has been largely anecdotal. There is a need for biocontrol researchers to define pre and post agent-release monitoring goals that will facilitate identification of negative impacts on invaded-community structure and/or function as well as evaluation of agent performance and community response to weed suppression. The biological control program for *Lythrum salicaria* L. (purple loosestrife) is an example of a well coordinated, successful post-release monitoring program that was based in part on Blossey's (1999) recommendations and has facilitated follow-up evaluation of the program (Kaufman and Landis 2000, Blossey et al. 2001b, Katovich et al. 2001, Landis et al. 2003).

STUDY SPECIES

Alliaria petiolata (M. Bieb) Cavara and Grande (garlic mustard) is a biennial invasive weed of European origin. First recorded on Long Island, New York in 1868 (Nuzzo 1993), it is now widely distributed and invasive in North America (Nuzzo 1993, 2000). It is notable among invaders in its ability to penetrate high quality forest understories as well as disturbed areas. Previous studies indicate that *A. petiolata* growth rates and fecundity are positively correlated with light availability (Meekins and McCarthy 2000) and that *A. petiolata* responds positively to the formation of canopy gaps (Luken et al. 1997). Current research suggests that exotic earthworms which increase litter cycling rates may be correlated with increased *A. petiolata* abundance (Bohlen et al. 2004, Hale et al. 2005, C.M. Hale personal communication 2003). Prati and Bossdorf (2004) demonstrated that *A. petiolata* may have allelopathic properties which could be mediated through suppression of arbuscular mycorrhizal fungi (Wolfe and Klironomos 2005).

Alliaria petiolata seedlings emerge at high densities in early spring and grow over the summer to form low rosettes of petiolate leaves. Seedling mortality over the summer is high with fewer than 20% of seedlings surviving to the rosette stage in southern Michigan in 2005 (Davis et al. 2005). Rosettes overwinter as green plants and bolt, flower (henceforth "adults"), senesce, and set seeds in late spring of the second year. Overwintering rosette survival in southern Michigan ranged from 52 – 89% from 2004 – 2005 (Davis et al. 2004). Seeds are produced in siliques along the upper stem and are released from mid summer though mid autumn. Seeds can remain viable in the soil for at least eight years (Nuzzo and Blossey unpublished data). The longevity of the seedbank dictates that any effective control efforts will have to be sustained over many years until the seed supply is exhausted. For all but the smallest infestations, this requirement is not practically achievable for most managers.

A search for suitable biological control agents for *A. petiolata* was initiated in 1998 (Hinz and Gerber 1998, Blossey et al. 2001a) with efforts now focused on four weevils in the genus *Ceutorhynchus* (Coleoptera: Curculionidae) that target multiple stages in *A. petiolata*'s life cycle (Hinz and Gerber 2000, 2001, Gerber et al. 2002, Gerber et al. 2003, Gerber et al. 2004). Biological control agents are not yet available for control of *A. petiolata* in North America. Thus, it is desirable to collect data on the target weed and invaded communities in advance of the anticipated natural enemy releases.

OBJECTIVES

In 2003 permanent sampling quadrats were established at eight forests in southern Michigan where *A. petiolata* occurred. My objectives were to (1) describe the study sites and invaded communities prior to any biocontrol agents releases, (2) determine whether Michigan *A. petiolata* populations are spreading within infested sites, and (3) measure the degree to which existing herbivores are impacting *A. petiolata* populations. These data will contribute to any future assessment of natural enemy releases. If biological control agents for *A. petiolata* are approved for release in the future, initial test releases may be made at a subset of these sites to allow comparisons of pre and post-release community dynamics and to evaluate the effectiveness of the agents. Here I present data on populations of *A. petiolata* prior to the introduction of insect biological control agents.

METHODS AND MATERIALS

SITE SELECTION

Lab personnel established eight study sites within *A. petiolata*'s primary range in Michigan's southern Lower Peninsula (Landis et al. 2004). Criteria for site selection included (1) forested lands > 2 ha in extent, (2) under state, federal, or other long-term conservation management, (3) on which *A. petiolata* populations have been established for at least four years, and (4) with protection from future disturbance or *A. petiolata* management for at least ten years. In spring of 2003 we recorded GPS coordinates for each site. We then marked 10 permanent 0.5 m^2 sampling quadrats (0.5 x 1 m) along each of two parallel, 100 m long transects spaced 10 m apart at seven sites and a single 200 m transect with quadrats spaced 10 m part at the eighth site (Russ Forest) for a total or 20 quadrats per site. Site inventories included data on forest type (MNFI 2003), maturity (diameter at breast height of principal overstory trees), and understory composition. Because accurate records of species composition were not kept at these sites before the initiation of this study, it is not possible to determine exactly how long *A. petiolata* had been present at any of them prior to 2003, although the extent of the invasions and anecdotal evidence from managers indicated that they met the criteria listed above.

ALLIARIA PETIOLATA EVALUATIONS

I collected data on *A. petiolata* distribution and abundance in accordance with a nationally standardized protocol (Nuzzo and Blossey unpublished). In spring (June) and fall (Sept. – Nov.) of 2003 – 2005 I visited each site and recorded data from each quadrat including: vegetation cover (*A. petiolata* total, *A. petiolata* by adult, seedling, and rosette stage plants, total non-*A. petiolata* vegetation and non A. *petiolata* vegetation by species), counts of *A. petiolata* adults, seedlings and rosettes, percent cover of substrate (bare soil, leaf litter, woody debris, and rock sum to 100%), and litter depth (cm). I recorded damage to *A. petiolata* plants as the estimated percent of leaf area removed and identified nine categories of damage to *A. petiolata* as either present or absent in each quadrat (leaf mining, windowpaning, edge feeding, holes, spittle bug, scale damage, browse, disease, and other). Finally, I recorded the height of and the number of siliques on each mature second year plant during the spring sampling period.

In contrast to the methods outlined by Nuzzo and Blossey (unpublished), not all sampling quadrats at each site contained *A. petiolata* at the initiation of the study. Rather, the transects traversed the *A. petiolata* invasion front where possible. This was done to allow us to measure spatial spread of *A. petiolata* populations within sites. At one site (Fernwood) this was not possible as all 20 quadrats there contained *A. petiolata* from the outset of the study. Plant community data are discussed in Chapter 3.

SITE DESCRIPTIONS

The Michigan Natural Features Inventory (MNFI) has identified 74 community-types that occur in Michigan (MNFI 2003). I used data on the identities, sizes, and abundances of the principal canopy trees as well as physical features of the sites and the inventories of all ground-layer vascular plant species that occurred in the sampling quadrats from June 2003 to October 2005 to describe each site in terms of the MNFI community types. The General Land Office (GLO), which was established by the United States federal government in 1785, systematically surveyed Michigan from 1816 through 1856 and made detailed records of soils, water resources, forests, and other natural features (MNFI 2005). The MNFI has interpreted the GLO data and created maps of early nineteenth century Michigan vegetation (MNFI 2005) with which I compared the current communities. In the site descriptions I have include an overview of the site topography, any important known or probable disturbances, important overstory and understory plant species, and the native species and total species richness that I observed in the sampling quadrats.

The eight sites selected are distributed across the southern four tiers of Michigan counties and represent a diverse assortment of *A. petiolata*-invaded forest types ranging from Southern Floodplain Forest to Dry Southern Forest (Figure 2, Table 1). A summary of the data used in the analyses that follow is presented in Table 2 and Appendices 1 and 2.

Study Sites

Box Woodlot: Box Woodlot is an isolated mesic southern forest (MNFI 2003) surrounded by crop fields with a gravel road along one edge. The overstory is dominated by large *Acer saccharum* (sugar maple) and *A. saccharinum* (silver maple) with *Fagus grandifolia* (American beech) and *A. rubrum* (red maple) occurring less frequently. Vegetation circa 1800 data shows the site as shrub swamp/emergent marsh and mesic southern forest (MNFI 2005). Anthropogenic influences such as isolation, selective cutting and drainage have affected changes in community structure. *Alliaria petiolata* is present throughout the site. Box Woodlot has the lowest plant species richness of the eight study sites with 17 species documented in the sampling quadrats, 16 of which are native.

Fernwood: The Fernwood Botanic Garden site is a mature dry-mesic southern forest (MNFI 2003) adjacent to an open community of old fields and restored native prairie. The overstory is dominated by *Quercus alba* (white oak), *Q. rubra* (red oak), *Q. velutina* (black oak), and *Prunus serotina* (black cherry). Prior to settlement the site was broadly classified as mesic southern forest (MNFI 2005). The sampling transects traverse several steep, minor drainages. The transects are approximately perpendicular to the primary slope of the hill and parallel to the forest edge 10 to 20 meters away. *Alliaria petiolata* abundance is greatest along the forest boundary but dense populations persist throughout the interior as well. Frequent deer trails, foot paths, and down-slope drainage are likely means of *A. petiolata* seed dispersal into the forest interior. This site has intermediate species richness with 43 species occurring in the quadrats, 41 of which are native. *Alliaria petiolata* had the largest spatial distribution at this site over the whole study period and occurred in 20/20 sampling quadrats.

Fort Custer: Fort Custer is a gently sloping dry-mesic southern to dry southern forest (MNFI 2003) whose canopy is dominated by large *Q. velutina*, *Q. alba* and *Carya ovata* (shagbark hickory) and borders previously disturbed areas along a two-track military access road. Pre-settlement vegetation surveys indicate the site as former mixed oak savanna (MNFI 2005) the largest oaks still showing an open-grown canopy structure. Suppression of fire has transformed the site to closed-canopy forest and led to loss of understory prairie species, although infrequent savanna-like openings persist at the site. *Alliaria petiolata* abundance is heaviest along the forest edge near the access road and in the openings but penetrates the entire forest. Military vehicle and foot traffic along the road and deer trails through the forest interior appear to be the primary means of *A. petiolata* dispersal. Fort Custer had the second highest species richness of the eight study sites with 58 species recorded in the quadrats, 52 of which are native. Invasion by *Berberis thunbergii* (Japanese barberry), *Rosa multiflora* (multiflora rose), and *Lonicera spp.* (bush honeysuckles) is also occurring at this site.

Ives Road: The Ives Road Fen Preserve is a 267 hectare property owned and managed by The Nature Conservancy that contains a mix of fen, restored native prairie, southern floodplain forest, and dry-mesic southern forest habitats (MNFI 2005). The study transects quarter a steeply sloping ecotone of mature dry-mesic southern forest that separates the upland restored prairie from the southern floodplain forest. Vegetation circa 1800 data show the lowlands as mixed hardwood swamp bordered by black oak barrens (MNFI 2005) The ecotone is too narrow to be resolved on the circa 1800 vegetation maps. However, the dominant canopy trees include *Q. alba*, *Q. rubra* and *C. ovata* indicating its coarse soil structure.

Alliaria petiolata stands appear most robust along the forest/prairie interface and decline in stature and density as the transects descend towards the bottomlands. *Alliaria petiolata* populations in the bottomlands are characterized by large, robust plants at medium to high densities. The population on the floodplain is addressed in a separate study (Davis et al. 2005). I recorded 48 species in the sampling quadrats at this site, 44 of which are native. *Alliaria petiolata* is the most abundant non-native invasive plant species at the Ives Road site, but *Lonicera spp.*, *R. multiflora*, *Hesperis matronalis* (dame's rocket), *Euonymus alata* (winged burning bush), and *Ligustrum spp.* (privet) also occur.

Lux Arbor: Lux Arbor is characterized as a mature dry-mesic southern forest in a bottomland grading up a hill into dry southern forest (MNFI 2003). The canopy is dominated by mature *Quercus velutina* and *Q. rubra* with an understory of modest species richness including several *Rubus* species (brambles) and *Phytolacca americana* (pokeweed). Circa 1800 vegetation data shows the site classified as mixed oak savanna (MNFI 2005). In spring 2005 logging activities led to major changes in canopy density and woody debris at ground level. Most large trees were cleared resulting in greatly increased light availability and substantial soil disturbance. In late spring 2005 I located and re-marked quadrats damaged by logging equipment and continued with normal sampling. *Alliaria petiolata* occurs throughout this site but is most abundant in the more mesic lowland and at the crest of the hill than along the hillside. At Lux Arbor 38 species have been recorded in the sampling quadrats, 34 of which are native. Continued monitoring at this site may reveal information on *A. petiolata*'s response to disturbance and changes in light availability at the population level.

Pinckney: The sampling area at Pinckney State Recreation Area is located in a well-drained, mature, dry-mesic southern forest on a gently sloping hillside. Canopy dominants in this system are large *Quercus rubra*, *Q. alba*, and *Carya ovata*, with a diverse understory community including *Cornus florida* and *C. foemina* (flowering and gray dogwoods), *Amelancheir spp.* (serviceberry), and *Sassafras albidus* (sassafras). The two transects are aligned transverse to the slope of the hill. *Alliaria petiolata* is present throughout the site, although abundance is heterogeneous and appears to track animal and foot trails which likely serve as dispersal corridors. Human activities at Pinckney include mountain biking and hiking along a trail approximately 10 – 30 m from the study site and hunting which draws limited foot traffic directly through the sampling area. At the Pinckney site 39 species occur in the quadrats, 38 of which are native.

Russ Forest: Russ Forest is an old growth dry southern forest (MNFI 2003) dominated by *Quercus alba* and *Q. velutina*. Large *Acer saccharum*, *Prunus serotina*, and *Liriodendron tulilpifera* (tulip tree) trees are also present and *A. saccharum* constitutes the majority of sub-canopy trees. Circa 1800 vegetation maps show the site as mixed oak savanna and mesic southern forest (MNFI 2005). The site topography is flat and level. Two roads border Russ Forest along its northern and western edges. *Alliaria* populations are well established and robust along the forest border to the north and diminish in evenness and density towards the forest interior. This site has a single, 200 m long transect consisting of 20 evenly spaced sampling quadrats that run parallel to the road which is approximately 15 – 20 m to the north. Russ Forest has lower species richness with 32 species observed in the sampling quadrats, 31 of which are native.

High winds produced during a storm event in the spring of 2004 caused a major blow-down in the northwest corner of the forest. The core blow-down area was completely deforested and is approximately 2 ha in size. Six quadrats at the western end of the transect are either in or near large treefall gaps created by the storm. Subsequent salvage logging operations conducted with horse teams and conventional skidders resulted in soil disturbance. Forest managers instructed logging crews to avoid the *A.*

petiolata study area and established a no-entry perimeter that extended approximately 20 m from the sampling areas for this and a separate study in the same forest.

Shiawassee: The Shiawassee YMCA Camp site is classified as southern floodplain forest (MNFI 2003) and is located on the floodplain of the Shiawassee River. Two parallel transects run from the first bottom of the river plain, which is dominated by *Acer saccharinum* and *Fraxinus pennsylvanica* and has a relatively open canopy, up a small rise to the second bottom of the river valley (Tepley et al. 2004), which is dominated by *Juglans nigra* (black walnut) and adjoins a two-track service road/foot path and *Pinus sylvestris* (scotch pine) plantation. Prior to settlement the site was classified as mesic southern forest (MNFI 2005), although it is doubtful that the actual floodplain would have supported that community type. *Alliaria petiolata* density is high throughout the site. Plant densities and adult plant sizes are exceptionally high in the second and first bottom floodplain areas, respectively. Second year *A. petiolata* plants on the first bottom were typically multi-stemmed and produced high numbers of seeds. However, the lowest areas, in which greater than 50% of the quadrats are located, are subject to periodic flooding. Flooding eliminated all seedlings and new rosettes from the first bottom areas in the late spring of 2004. Second year plants had already flowered and produced seeds, although they had all been knocked down by the flood. I was able to measure heights and estimate fecundity of the downed second year plants, although this required handling plants to separate and measure matted stems. Shiawassee had the highest species richness of all eight sites. I identified 59 species in the sampling quadrats at Shiawassee, 53 of which were native.

ANALYSES OF DATA

Spread of *Alliaria petiolata*

A portion of the sampling quadrats at seven of the eight sites had not yet been invaded when the study was initiated in 2003. I coded each quadrat as either invaded or uninvaded for each sampling period based on the presence of absence of live *A. petiolata* plants. I tested for linear trends in the number of invaded quadrats per site over time with a repeated measures general linear model in SAS version 8.2 using the REPEATED command in PROC GLM (SAS Institute 2001). I tested assumptions of compound symmetry with Mauchly's sphericity test applied to orthogonal components and evaluated linear trends pending those findings. I tested the significance of changes in the mean number of invaded quadrats within-sites using Dunn-Sidak adjusted (Gotelli and Ellison 2004) pairwise comparisons in SYSTAT version 11.0 (SYSTAT Inc. 2004). Both first and second year *A. petiolata* plants were present during spring sampling, but second year plants senesced each year prior to fall sampling. Because first and second year plants were often spatially segregated, the fall data do not reflect the full distribution of *A. petiolata* within each site. I used only spring data in the spatial-spread analysis for this reason, although I present the fall data graphically.

Estimation of *Alliaria petiolata* Fecundity

To estimate fecundity of *A. petiolata* plants, I collected 130 mature plants from six locations in southern Michigan (Edward Lowe Foundation, Cassopolis; Gasinski Farm, Springville; Holland State Park, Holland; Johnson State Park, Wyoming; Rose Lake Wildlife Management Area, East Lansing; Shiawassee YMCA Camp, Bancroft) and measured the height and number of siliques on each. I dissected the seeds from each plant and counted them using an automated seed counter (SeedBuro model 801 Count-A-Pac Seed Counter ®, SeedBuro Equipment Co., Chicago, IL). Linear regression of number of seeds x plant^{-1} on number of siliques x plant^{-1} (R Development Core Team 2004) allowed fecundity estimates for plants with known numbers of siliques.

Calculation of Survival Probabilities

I calculated survival probabilities for seedling to rosette ("seedling survival") and rosette to adult plant ("rosette survival") transitions for *A. petiolata* plants in each sampling quadrat at each site. Seedling survival is expressed as the number of seedlings observed during the spring sampling period divided into the number of rosettes observed during the fall sampling period of the same year, giving the proportion of seedlings that survived the summer. Rosette survival was similarly calculated by dividing the number of rosettes observed during the fall sampling period into the number of flowering adult plants observed during the spring of the following year.

Seedling mortality extends from the beginning of the germination period in late March through the summer (Evans unpublished data). My sampling methods captured the number of seedlings present during a single visit but did not account for seedling mortality prior to spring sampling or germination and mortality of additional seeds between spring and fall sampling. Thus, the estimates of seedling survival are useful for between-site comparisons but are not true estimates of *A. petiolata* demographic parameters. Because the study included three summers and two winters, there are three estimates of seedling survival but only two estimates of rosette survival.

Sampling Error

I detected two forms of observational error in my data. There were 16 cases where fewer seedlings were recorded in spring than the number of rosettes observed in fall and nine similar cases where fewer rosettes were observed in fall than flowering plants the following spring, which generated survival probabilities greater than one. Also there were 20 cases where rosettes were recorded where no seedling had been recorded in the spring and nine cases where flowering plants were observed where no rosettes had been recorded the previous fall (divide by zero error). These errors most often occurred where *A. petiolata* density was lowest and the overlooked plant(s) represented a greater proportion of the quadrat total. These 54 observations were omitted from analyses. Future estimation of sampling error may allow correction of these observations and allow accounting for future errors.

Herbivore Impacts on *Alliaria petiolata*

I tested for impacts of herbivore damage on *A. petiolata* per capita fecundity and both seedling and rosette survival using regression tree analyses. Regression trees are distribution-free multivariate analyses that allow specification of both categorical and continuous independent variables to predict continuous dependent variables. I specified the presence or absence of the nine categories of damage to *A. petiolata*, estimated percent leaf damage to *A. petiolata*, site, and year as independent variables in each regression tree. I also included quadrat level species richness as an independent variable to explore whether it was more predictive of survival and fecundity than herbivores or other damage sources. I used data on species richness and damage to rosettes in fall to separately predict overwintering rosette survival and fecundity in the following spring which allowed for two winters' data to be included (fall 2003 – spring 2004 and fall 2004 – spring 2005). I used spring data to again identify predictors of fecundity and to identify predictors of seedling survival.

The regression tree algorithm uses pre-specified criteria to divide the dataset into increasingly homogeneous subgroups as measured in the independent variable and reports the mean, standard deviation, and number of observations in each subgroup. The proportion of reduction in error (PRE) is a measure of model fit equivalent to an R^2 statistic that describes the fit of the overall model and the improvement in model fit contributed by each split in the data. The stopping and splitting criteria can be adjusted to avoid over-specification of the model and maximize interpretability of the final tree. In each regression tree analysis I set the maximum number of splits to five, the minimum PRE for each split to 0.05, the minimum proportion of the dataset partitioned at each split to 0.05, and the minimum number of observations in each terminal group to five. The data are split until the maximum number of splits is reached or until further splits do not meet the other three stopping criteria. All errors shown are ± one standard error.

RESULTS AND DISCUSSION

EXPANSION OF *ALLIARIA PETIOLATA* WITHIN SITES

The spatial distribution of *A. petiolata* increased at seven of the eight sites from 2003 to 2005 (Figure 3). At the Fernwood site all 20 quadrats were originally invaded, and detection of spread was not possible. All 20 quadrats remained invaded for the duration of the study at this site, and Fernwood was thus excluded from analyses of spread. In the spring of 2003, the number of sampling quadrats (n = 20) that contained *A. petiolata* at the seven other sites ranged from 7 – 18 (mean = 11.9) (Table 3). By spring of 2004, this range had shifted to 11 – 18 (mean = 15.9) quadrats invaded per site and to 11 – 20 (mean = 16.4) by spring of 2005. Across these seven sites, the mean percent increase in the number of quadrats invaded from spring of 2003 to spring of 2005 was 45.9 ± 12.1% (range 5.6 – 100%). An average of 59.0 ± 9.0% (range 30.8 – 100%) of initially uninvaded quadrats became invaded over this same period (Table 3).

The change in the number of invaded quadrats per site over time was significant in a repeated measures analysis (Table 4). The assumptions of sphericity and homogeneity of variance were both satisfied (Mauchly's criterion = 0.8143, $df = 2$, χ^2 = 1.0269, P = 0.5984, Levene's Test P = 0.4238). The main effect of year on the number of invaded quadrats was significant indicating a change in the distribution of *A. petiolata* within sites over time ($F_{2, 12}$ = 11.8575, P = 0.0014). Although change in the number of invaded quadrats per site was not significant during either one-year time step, over the two year period from spring 2003 to spring 2005 the increase was significant and positive (Table 5, *D-S* adjusted P = 0.0154) at 45.9% increase per 2 years. While it would be desirable to estimate the rate of *A. petiolata* spread either within sites or across the landscape, these data are not suited to that purpose. Nuzzo's (1999) study of *A. petiolata* spread in Illinois concluded that populations expanded at a mean rate of approximately 5.4 m/year, which may be similar to the rate of spread at some of these sites and may be lower than the rates I saw at others.

These findings offer quantitative support for the frequent observation that *A. petiolata* populations almost invariably expand within sites once established. Populations do fluctuate in density from year to year (Figure 4) which may result from density dependent effects, competition between first and second year plants (Winterer et al. 2005), or response to variable environmental conditions and interactions with the receiving community. The sharp decline in *A. petiolata* abundance at Shiawassee in fall of 2004 resulted from the drowning of most seedlings during the flood that spring. This was offset by the large emergence of seedlings the following year. Seasonal variation in abundance (Table 2) is primarily an artifact of *A. petiolata*'s biennial life cycle. Both seedlings and adults are present during the spring sampling period, but adults senesce in mid-summer leaving just rosettes in the fall counts. The increasing number of invaded quadrats coupled with lower percent cover in newly invaded quadrats explains the apparent overall decline in *A. petiolata* cover over time (Figure 5), although the decreases in mean *A. petiolata* cover from 2004 to 2005 may be due in part to environmental conditions such as reduced precipitation in 2005. Over time, I expect that newly invaded quadrats should increase in *A. petiolata* cover to the same levels as quadrats that were initially invaded.

ESTIMATION OF *ALLIARIA PETIOLATA* FECUNDITY

The ratio of seeds per plant to siliques per plant was invariant across sites (Figure 6). I counted the seeds from 132 *A. petiolata* plants collected from multiple locations across southern Michigan. Plants ranged in number of siliques from zero to 266 and had from zero to 3,864 seeds. The linear regression of the number of seeds versus siliques had a slope of 14.587 ($R^2 = 0.9806$), meaning that each siliques contained an average of 14.6 seeds.

ALLIARIA PETIOLATA DAMAGE BY HERBIVORES

I observed damage to *A. petiolata* plants 536 out of the 631 times (84.9%) that sampling quadrats contained *A. petiolata* across all sites and years (of 960 total quadrat observations). However, the mean proportion of *A. petiolata* leaf area damaged or consumed per quadrat was estimated to be only 2.9 ± 2.2% across all sampling dates, and incidence of more substantial damage was infrequent (Figure 7).

Spring damage

Within the subset of quadrats that contained *A. petiolata* plants across all sites and years, I observed leaf edge feeding damage in an average of 41.6% (range 13.0 – 62.5%) quadrats $sampling^{-1}$, leaf hole damage in 79.4% (range by site 48.1 – 98.2%), and windowpaning in 7.1% (range 0 – 35.0%) of sampling quadrats. I recorded browse by larger herbivores (i.e. deer, woodchucks) at four sites with damage occurring in 2.8 – 5% of quadrats. The majority of sampling quadrats at the Shiawassee site are located on the Shiawassee river floodplain, which was substantially flooded during the spring of 2004. This accounts for the high *A. petiolata* seedling mortality observed during that season, which was recorded here as "other" damage.

Diseases on A. petiolata in Michigan: I observed diseased plants at one site in spring 2003 and at three sites in spring 2005 with 1.7 – 8% of quadrats containing diseased plants within those sites. Plants from Ives Road in spring of 2005 had virus-like symptoms but tested negative for cucumber mosaic virus (CMV). Diseased plants were stunted with unusual growth patterns that included highly convoluted leaf surfaces and siliques. Plants with these symptoms were typically grouped close together within a site and were seen at Russ Forest and at the Kellogg Biological Station Bird Sanctuary in Hickory Corners, MI. Wilted plants in Springville, MI (approximately 20 km west-northwest of the Ives Road site) tested positive for *Pythium sp.* (personal communication Jan Byrne, Mich. State Univ. Plant Disease Diagnostician, Diagnostic Services May 18, 2005), and fungal growths that caused weakening of *A. petiolata* stems at a site approximately 6 km south of Russ Forest were identified as *Sclerotinia sclerotiorum* (white mold) by Pat Hart (personal communication. Mich. State Univ. Department of Plant Pathology, May, 2004).

Fall damage

The damage types I observed in the spring were also most common in the fall. Edge feeding damage occurred in an average of 65.0% (range = 47.8 – 80.0%) quadrats site^{-1} sampling^{-1}, leaf hole damage in 75.7% (range 44.1 – 97.4%), and windowpaning in 22.6% (range 0 – 32.1%) of quadrats site^{-1} sampling^{-1}. I saw evidence of browse only once during fall sampling at one site and disease only twice. Diseased plants at Lux Arbor appeared to be virally infected as described above, but those at Shiawassee were only yellowed and not wilted.

Extensively Damaged Quadrats

In most quadrats *A. petiolata* was not accepted for sustained feeding by herbivores, and feeding damage was therefore limited to "tasting" followed by rejection. However, the few quadrats in which *A. petiolata* was more extensively damaged are of special interest because they suggest the possible existence of local populations of herbivores that are more accepting of *A. petiolata*. With the exception of flood damage at Shiawassee in spring 2004, there were only 33 quadrats with greater than 10% leaf area damaged, 28 of which were observed during fall sampling. Most of these represented feeding in quadrats containing a small number of *A. petiolata* plants which may give a false impression of extensive damage. Nearly all quadrats with high damage estimates had holes and edge-feeding damage.

The most interesting cases were in four quadrats: two each from Fernwood in fall 2003 and Lux Arbor in spring 2004 with higher *A. petiolata* cover (10 – 45%) which sustained 10 – 20% leaf area damage. Each or these four quadrats had damage from edge feeding insects and holes from other herbivorous invertebrates, and one at Lux Arbor had been browsed by deer. The extensive edge and hole damage in one quadrat at Lux Arbor (20% damage in a quadrat with 45% *A. petiolata* cover) may be worth monitoring in the future. If local populations of herbivores at some locations are capable of feeding on *A. petiolata* and taking advantage of it as an abundant food source, it is possible that they could multiply and spread to other locations.

Despite the widespread presence of herbivore damage, total leaf area removed averaged 2.1% (range 0.3 – 9.5%) across all sites and years in spring and 4% (range 0.9 – 8.9%) in fall. The highest damage estimate represents the effects of the flood at Shiawassee.

Impacts of Damage

Regression tree analyses indicated non-negative or no relationships between survival or fecundity estimates and the presence or extent of *A. petiolata* damage. *Alliaria petiolata* fecundity and overwintering rosette survival were not correlated with any measures of *A. petiolata* damage in fall, year, or site when site was included as an independent variable. Removing the term for site and relaxing the splitting criteria to allow splits to improve fit (PRE) by 0.025 rather than 0.05 and lowering the minimum terminal group size to 3 from 5 did allow estimation of effects on overwintering survival, but all findings were insignificant (Figure 8). The insignificant model as fit showed higher survival where holes damage was present, and among quadrats without holes-damage survival was insignificantly higher in the winter of 2004 – 2005 than 2003 – 2004. Using spring damage data to predict fecundity was again not significant as was the relationship with seedling survival. Relaxing the fit criteria still did not allow fitting of a model to the predict fecundity. However, when site was removed as a predictor, seedling survival was positively correlated with percent damage to *A. petiolata,* but the fit was not significant (Figure 9, PRE = 0.0557) and only partitioned out 24 of 306 observations.

These analyses show that the impacts of herbivores, browsing animals, and other forms of damage to *A. petiolata* as well as site species richness and differences between sites are not significantly correlated with *A. petiolata* survival or fecundity. This suggests that although *A. petiolata* plants were minimally fed upon in the majority of quadrats, this feeding had positive impact on *A. petiolata* performance if any. It is possible that *A. petiolata* overcompensated for damage, but because the correlations were not significant, further speculation about their nature is not warranted.

CONCLUSIONS

Alliaria petiolata populations are expanding within invaded forests in Michigan. This trend is significant across seven locations where measurement of spread was possible. At an eighth sampling location the population had completely invaded the study area from the initiation of sampling in spring of 2003. Although I was not able to detect increase in the spatial distribution of *A. petiolata* at this site, I was able to show that the distribution has not decreased over the course of the study.

Surprisingly, I found that *A. petiolata* plants are almost universally fed upon by herbivores across southern Michigan. However, damage to plants rarely exceeded 2% of the total leaf area in a quadrat. Although widespread, this feeding appears to have no impact on *A. petiolata* survival or fecundity as I measured it. Because I only sampled each site twice annually, the measures of survival that I used are simplified and do not represent the true demographic rates of these transitions. However, because all sampling was done in a short time period each year, using these rates for comparisons between sites is appropriate. Variation in *A. petiolata* demographic parameters across southern Michigan is the focus of other ongoing research and can be better used to make predictions about *A. petiolata* population growth (Davis et al. 2005).

The data presented here paint a portrait of an invasive weed that is spreading rapidly into new habitats and is unchecked by natural enemies. These data show that, in Michigan, damage to *A. petiolata* from herbivores is not biologically significant. Increasing herbivore damage to invading *A. petiolata* populations with introduced natural enemies may present a new opportunity to slow or reverse its spread. Given the potential for *A. petiolata* to cause harm to the communities that it invades as others have shown (e.g. Stinson and Klironomos 2005) and the ineffectiveness of conventional controls, classical biological control agents may be recommended for *A. petiolata* in Michigan if agents are approved for release in the future. If natural enemy agents are released, these data will provide a useful benchmark for evaluating their performance.

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Table 1. Michigan sites selected for long-term monitoring of garlic mustard

Site Name	County	Latitude	Longitude	Dominant Canopy Trees (DBH cm)	MNFI Community Type
Box Woodlot	Ingham	42.689479°	-84.489951°	sugar maple (67, 74), silver maple (82, 80), bur oak (69, 67), sycamore (74), green ash (46, 35)	Southern Mesic Forest
Fernwood	Berrien	41.867417°	-86.346351°	White oak (44), red oak (80), tulip tree (51, 60), black walnut (33, 56, 64), hackberry (12), American elm (54), redbud (25), black oak, black cherry	Dry-Mesic Southern Forest
Ft. Custer	Kalamazoo	42.305018°	-85.325651°	Black oak (81), white oak (77, 78), shagbark hickory (76), sugar maple (76), black walnut (43, 46)	Dry-Mesic Southern Forest
Ives Road	Lenawee	41.980206°	-83.932771°	White oak (91), red oak, shagbark hickory	Dry-Mesic Southern Forest
Lux Arbor	Barry	42.492880°	-85.466543°	Red oak (66, 89), white oak (46, 63), black cherry (46)	Dry-Mesic/Dry Southern Forest
Pinckney	Livingston	42.440907°	-84.005645°	White oak (105), black walnut (17), black cherry (51), sugar maple (18), red oak (40)	Dry-Mesic Southern Forest
Russ Forest	Cass	42.011616°	-85.970255°	Black oak (83), white oak (79, 83), black cherry (30, 49), tulip tree (84)	Dry Southern Forest
Shiawassee	Shiawassee	42.885813°	-84.046135°	Silver maple (28), cottonwood (256, 81), black walnut (92), red ash (54), black cherry (43), basswood (39), hackberry (29)	Southern Floodplain Forest

Table 2. Summary of data by site and sampling period ± 1 SE where applicable. Percent cover data were estimated separately for seedling and adult *A. petiolata* plants as well as overall in spring. Total *A. petiolata* cover in fall represents rosette cover because no seedlings or adults are present at that time. Estimates of mean *A. petiolata* height, fecundity and presence and extent of damage to *A. petiolata* plants is calculated from quadrats that contained *A. petiolata* plants, although *A. petiolata* percent cover and counts represent site means in both invaded and uninvaded quadrats. During the six sampling periods from 2003 – 2005 there were a total of 960 quadrat observations from 20 quadrats at each of eight sites.

All Sampling Dates Combined

Data Type	Box Woodlot	Fernwood	Ft. Custer	Ives Rd.	Lux Arbor	Pinckney	Russ Forest	Shiawassee
Number of Quadrats Invaded	81	113	52	91	75	80	53	86
Total *A. petolata* Cover	9.0 ± 2.9	23.0 ± 6.1	6.9 ± 3.2	3.2 ± 1.8	9.1 ± 3.5	4.2 ± 1.9	2.3 ± 1.5	20.0 ± 6.2
Adult Cover (%)	9.0 ± 2.9	11.0 ± 4.1	5.0 ± 3.3	2.7 ± 1.7	4.1 ± 1.8	2.5 ± 1.1	2.0 ± 1	14.2 ± 5.6
Seedling Cover (%)	7.3 ± 2.7	33.8 ± 6.2	7.2 ± 2.9	3.4 ± 1.9	6.8 ± 3.2	5.5 ± 2.4	2.2 ± 1.8	16.4 ± 5.6
Leaf Damage (% removed)	2.3 ± 1.5	2.1 ± 1.2	1.1 ± 0.5	1.6 ± 1.9	5.9 ± 2.5	2.1 ± 1.3	1.0 ± 0.5	6.6 ± 4.5
Windowpane Damage (%)	0.0 ± 0	0.2 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.0 ± 0	0.1 ± 0.1
Edge Feeding Damage (%)	0.6 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.7 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.5 ± 0.1
Holes Damage (%)	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.6 ± 0.1	0.9 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.9 ± 0.1
Browse Damage (%)	0.0 ± 0	0.0 ± 0	0	0	0.0 ± 0	0	0.0 ± 0	0
Disease Damage (%)	0.0 ± 0	0.0 ± 0	0	0	0.1 ± 0.1	0	0	0.1 ± 0.1
Other Damage (%)	0	0.0 ± 0	0	0	0	0	0	0.1 ± 0.1
Adults · $(0.5m^2)^{-1}$	3.1 ± 1.6	4.3 ± 1.9	5.1 ± 2.1	1.6 ± 1.2	2.4 ± 1.6	1.2 ± 1.0	1.2 ± 0.9	8.1 ± 4.8
Seedlings · $(0.5m^2)^{-1}$	20.2 ± 11.0	59.2 ± 23.0	22.6 ± 15.8	10.3 ± 5.7	15.4 ± 11.8	22.5 ± 12.6	5.4 ± 5.5	62.4 ± 33.3
Rosettes · $(0.5m^2)^{-1}$	5.1 ± 3.3	11.0 ± 4.5	3.4 ± 2.2	3.2 ± 2.0	7.8 ± 5.4	2.2 ± 1.2	1.5 ± 1.2	14.3 ± 7.2
Mean *A. petiolata* Height (cm)	37.4 ± 6.8	52.3 ± 8.1	54.6 ± 9.7	21.5 ± 5.4	57.6 ± 9.5	32.0 ± 9.3	31.6 ± 7.1	50.1 ± 10.5
Per Capita Fecundity	98.5 ± 27.6	222.5 ± 51.4	188.5 ± 50.8	45.5 ± 14.5	308.9 ± 73.9	124.4 ± 59.0	69.2 ± 20.3	217.2 ± 86.9
Other Vegeation Cover (%)	10.8 ± 3.4	17.3 ± 3.8	37.4 ± 5.5	25.8 ± 4.6	15.4 ± 4	41.7 ± 50.7	23.7 ± 4.1	51.7 ± 7.7
Soil Cover (%)	28.3 ± 6	6.5 ± 2.6	10.2 ± 3.7	34.5 ± 7.5	22.1 ± 6	25.0 ± 5.7	5.2 ± 2.8	71.6 ± 6.3
Wood Cover (%)	14.7 ± 3.3	7.3 ± 2.3	9.0 ± 2.8	15.3 ± 3.7	11.6 ± 2.6	8.3 ± 2.4	8.0 ± 3	11.6 ± 3.1
Leaf Cover (%)	56.9 ± 7	85.9 ± 3.6	80.8 ± 4.5	50.1 ± 7.6	64.6 ± 6.8	66.1 ± 6.6	86.8 ± 4	16.8 ± 5.6
Rock Cover (%)	0.0 ± 0	0.3 ± 0.2	0.0 ± 0	0.0 ± 0	1.6 ± 1.3	0.6 ± 1.4	0.0 ± 0	0.0 ± 0
Mean Litter Depth (cm)	1.9 ± 0.4	2.0 ± 0.3	1.9 ± 0.3	1.7 ± 0.4	1.8 ± 0.3	1.7 ± 0.2	2.6 ± 0.3	0.4 ± 0.2

Table 2. Continued

Spring 2003

Data Type	Box Woodlot	Fernwood	Ft. Custer	Ives Rd.	Lux Arbor	Pinckney	Russ Forest	Shiawassee
Number of Quadrats Invaded	16	20	7	18	9	10	9	14
Total *A. petolata* Cover (%)	15.8 ± 3.2	39.6 ± 5.1	10.0 ± 3.6	6.6 ± 2.8	7.8 ± 3.7	6.4 ± 2.1	3.9 ± 1.4	36.0 ± 6.5
Adult Cover (%)	13.5 ± 3.3	11.3 ± 3.9	1.5 ± 1.5	6.4 ± 2.8	4.1 ± 2.1	4.7 ± 1.6	3.3 ± 1.3	14.8 ± 4.4
Seedling Cover (%)	2.9 ± 1.4	32.2 ± 5	8.5 ± 3.2	0.4 ± 0.2	4.2 ± 3.2	2.1 ± 1.6	0.7 ± 0.3	24.5 ± 6.5
Leaf Damage (% removed)	0.5 ± 0	0.5 ± 0	0.4 ± 0	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.6 ± 0	0.5 ± 0
Windowpane Damage (%)	0	0	0	0	0	0	0	0
Edge Feeding Damage (%)	0	0	0	0	0	0	0	0
Holes Damage (%)	1.0 ± 0	0.9 ± 0.1	0.9 ± 0.1	0.6 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	1.0 ± 0	0.9 ± 0.1
Browse Damage (%)	0	0	0	0	0	0	0	0
Disease Damage (%)	0	0	0	0	0	0	0	0.1 ± 0.1
Other Damage (%)	0	0	0	0	0	0	0	0.1 ± 0.1
Adults · $(0.5m^2)^{-1}$	6.5 ± 1.5	7.2 ± 1.7	22.3 ± 0.9	5.5 ± 2.1	2.1 ± 1.1	4.4 ± 1.9	1.7 ± 0.7	24.9 ± 8.2
Seedlings · $(0.5m^2)^{-1}$	11.1 ± 5.1	76.7 ± 15.2	17.7 ± 7.8	2.3 ± 0.7	6.6 ± 5.0	7.4 ± 4.8	3.4 ± 1.4	151.7 ± 46.4
Mean *A. petiolata* Height (cm)	62.5 ± 5.1	57.6 ± 8.5	59.1 ± 2.7	40.8 ± 6	57.3 ± 10.4	47.5 ± 9.9	58.1 ± 5.7	56.7 ± 8.7
Per Capita Fecundity	183.4 ± 27.3	248.3 ± 44.4	84.0 ± 15.4	101.8 ± 17.7	283.7 ± 70.1	147.6 ± 39.6	164.6 ± 25.4	246.5 ± 108.5
Other Vegeation Cover (%)	15.6 ± 3.3	26.5 ± 3.9	59.0 ± 3.2	40.1 ± 4.5	17.1 ± 3	30.9 ± 3.7	38.0 ± 4.2	51.9 ± 6.8
Soil Cover (%)	16.9 ± 4.7	12.3 ± 4.3	1.9 ± 0.5	27.8 ± 5.9	7.5 ± 2.1	15.5 ± 4.5	1.2 ± 0.5	89.9 ± 2.4
Wood Cover (%)	8.3 ± 1.7	15.2 ± 4.7	18.2 ± 4.5	8.7 ± 2	12.3 ± 3.3	5.7 ± 1.9	5.2 ± 1.3	7.6 ± 1.7
Leaf Cover (%)	74.9 ± 4.8	72.3 ± 5.9	79.8 ± 4.4	63.5 ± 5.5	78.2 ± 4.4	78.8 ± 4.7	93.6 ± 1.4	2.5 ± 1.5
Rock Cover (%)	0	0.2 ± 0.1	0	0.0 ± 0	1.9 ± 1.6	0	0	0.1 ± 0.1
Mean Litter Depth (cm)	2.5 ± 0.2	0.7 ± 0.1	1.9 ± 0.3	2.2 ± 0.3	2.4 ± 0.2	2.0 ± 0.2	3.1 ± 0.2	0.1 ± 0.1

Table 2. Continued

Spring 2004

Data Type	Box Woodlot	Fernwood	Ft. Custer	Ives Rd.	Lux Arbor	Pinckney	Russ Forest	Shiawassee
Number of Quadrats Invaded	18	20	11	17	16	16	14	15
Total *A. petolata* Cover (%)	19.7 ± 3.8	50.0 ± 6.7	15.7 ± 5.2	7.3 ± 3.1	17.3 ± 4.1	11.0 ± 3.4	4.9 ± 2.9	31.1 ± 8.5
Adult Cover	3.4 ± 2.1	16.0 ± 5.5	12.9 ± 5.1	0	2.5 ± 0.8	0.9 ± 0.5	0.2 ± 0.1	20.4 ± 7.1
Seedling Cover	16.3 ± 3.7	34.8 ± 7.5	4.0 ± 2	7.3 ± 3.1	14.9 ± 3.9	10.3 ± 3.4	4.7 ± 3	11.0 ± 6.2
Leaf Damage (% removed)	1.0 ± 0.2	0.6 ± 0	0.5 ± 0	0.4 ± 0	5.3 ± 1.7	0.8 ± 0.3	1.5 ± 0.9	28.2 ± 9.2
Windowpane Damage (%)	0	0	0	0	0	0	0	0
Edge Feeding Damage (%)	1.0 ± 0	0.4 ± 0.1	0.6 ± 0.1	0.4 ± 0.1	0.6 ± 0.1	0.8 ± 0.1	0.4 ± 0.1	0.5 ± 0.1
Holes Damage (%)	0.9 ± 0.1	0.9 ± 0.1	1.0 ± 0	0.8 ± 0.1	1.0 ± 0	0.9 ± 0.1	0.6 ± 0.1	0.7 ± 0.1
Browse Damage (%)	0.1 ± 0.1	0.2 ± 0.1	0	0	0.1 ± 0.1	0	0.1 ± 0.1	0
Disease Damage (%)	0	0	0	0	0	0	0	0
Other Damage (%)	0	0.1 ± 0.1	0	0	0	0	0	0.7 ± 0.1
Adults · $(0.5m^2)^{-1}$	2.8 ± 1.9	12.7 ± 3.0	7.5 ± 2.6	0	1.1 ± 0.5	0.4 ± 0.2	0.3 ± 0.2	16.9 ± 4.9
Seedlings · $(0.5m^2)^{-1}$	88.0 ± 17.6	74.4 ± 14.8	23.0 ± 12.1	48.0 ± 10.1	76.4 ± 24.5	85.5 ± 22.6	24.1 ± 12.8	81.1 ± 48.6
Mean *A. petiolata* Height (cm)	18.3 ± 5.7	55.8 ± 6.7	84.4 ± 9.5	0	44.0 ± 10.9	19.2 ± 8.9	6.8 ± 4	79.0 ± 9.4
Per Capita Fecundity	63.1 ± 31.6	228.6 ± 52.8	391.3 ± 53.7	0	285.5 ± 88.4	150.9 ± 89.7	18.9 ± 12.8	336.1 ± 84.7
Other Vegeation Cover	15.6 ± 4.6	29.1 ± 4.3	59.0 ± 5.1	40.0 ± 4.6	18.9 ± 4.2	36.6 ± 3.3	25.4 ± 3.6	44.4 ± 7.1
Soil Cover (%)	35.0 ± 4.6	11.5 ± 3.1	6.0 ± 1.4	22.1 ± 7.3	17.7 ± 6.4	13.0 ± 2.7	1.6 ± 0.5	65.1 ± 7.3
Wood Cover (%)	29.8 ± 5.1	7.4 ± 1.4	8.6 ± 3.8	15.2 ± 4	6.8 ± 1	6.3 ± 1.7	11.5 ± 4.8	22.6 ± 5.4
Leaf Cover (%)	35.3 ± 4.8	81.1 ± 3.9	85.5 ± 4.7	62.7 ± 7.9	73.9 ± 7	80.8 ± 2.8	87.0 ± 4.8	12.3 ± 4.8
Rock Cover (%)	0	0.1 ± 0.1	0	0.1 ± 0	1.7 ± 1.3	0	0	0
Mean Litter Depth (cm)	1.6 ± 0.4	1.4 ± 0.2	1.8 ± 0.2	1.9 ± 0.4	1.8 ± 0.3	2.4 ± 0.3	3.1 ± 0.4	0.4 ± 0.1

Table 2. Continued

Spring 2005

Data Type	Box Woodlot	Fernwood	Ft. Custer	Ives Rd.	Lux Arbor	Pinckney	Russ Forest	Shiawassee
Number of Quadrats Invaded	19	20	11	19	15	20	13	18
Total *A. petolata* Cover (%)	12.3 ± 2.7	37.7 ± 6.1	9.9 ± 3.4	3.7 ± 1.2	6.7 ± 2.1	5.7 ± 1.2	3.3 ± 1.1	20.7 ± 5.6
Adult Cover (%)	10.0 ± 2.9	5.6 ± 1.6	0.7 ± 0.5	1.6 ± 0.6	5.6 ± 2.1	1.9 ± 0.5	2.6 ± 1	7.5 ± 4.8
Seedling Cover (%)	2.8 ± 1	34.4 ± 6.2	9.3 ± 3.4	2.4 ± 0.6	1.4 ± 0.4	4.1 ± 1.1	1.1 ± 0.4	13.8 ± 3.5
Leaf Damage (% removed)	1.0 ± 0	1.0 ± 0	0.9 ± 0.1	0.1 ± 0.1	2.7 ± 0.3	0.9 ± 0.1	1.0 ± 0.3	1.0 ± 0
Windowpane Damage (%)	0.1 ± 0.1	0	0.6 ± 0.1	0	0.9 ± 0.1	0.1 ± 0.1	0	0.1 ± 0.1
Edge Feeding Damage (%)	0.5 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.1 ± 0.1	1.0 ± 0	0.6 ± 0.1	0.5 ± 0.1	0.7 ± 0.1
Holes Damage (%)	0.9 ± 0.1	1.0 ± 0.1	0.9 ± 0.1	0.1 ± 0.1	1.0 ± 0	0.6 ± 0.1	0.3 ± 0.1	0.9 ± 0.1
Browse Damage (%)	0	0	0	0	0	0	0	0
Disease Damage (%)	0.1 ± 0.1	0.1 ± 0.1	0	0	0	0	0	0.1 ± 0.1
Other Damage (%)	0	0	0	0	0	0	0	0
Adults · $(0.5m^2)^{-1}$	9.2 ± 2.6	5.6 ± 1.6	0.7 ± 0.4	3.9 ± 1.6	11.5 ± 3.1	2.6 ± 1.1	5.4 ± 1.9	6.8 ± 4.6
Seedlings · $(0.5m^2)^{-1}$	22.0 ± 10.6	203.9 ± 34.5	94.8 ± 31.5	11.4 ± 3.2	9.7 ± 3.9	42.0 ± 11.8	4.8 ± 1.4	141.9 ± 32.4
Mean *A. petiolata* Height (cm)	34.4 ± 6	43.6 ± 8.9	22.0 ± 7.9	22.6 ± 3.6	72.3 ± 6.2	34.4 ± 9	40.0 ± 6.5	20.9 ± 9.3
Per Capita Fecundity	60.4 ± 13.5	190.6 ± 58.1	52.3 ± 23.1	32.7 ± 7.7	348.9 ± 62.4	91.7 ± 32.6	57.2 ± 10.1	95.4 ± 63.6
Other Vegeation Cover (%)	12.4 ± 4	24.8 ± 3	43.0 ± 3.3	33.2 ± 3.6	19.7 ± 3.9	23.4 ± 2.1	29.3 ± 4.9	64.5 ± 7.9
Soil Cover (%)	8.9 ± 1.8	3.6 ± 0.9	3.6 ± 1.2	28.5 ± 7.5	15.6 ± 6	9.2 ± 2.3	0.4 ± 0.2	79.0 ± 5.2
Wood Cover (%)	7.2 ± 1.2	5.9 ± 0.8	4.5 ± 1.1	12.4 ± 3	8.8 ± 2.1	3.3 ± 0.7	5.4 ± 0.9	6.3 ± 1.9
Leaf Cover (%)	84.0 ± 1.9	90.2 ± 1.1	92.0 ± 1.3	59.1 ± 7.3	75.0 ± 6.4	87.5 ± 2.2	94.2 ± 0.9	14.8 ± 4.9
Rock Cover (%)	0	0.4 ± 0.2	0	0.1 ± 0.1	0.8 ± 0.8	0	0	0
Mean Litter Depth (cm)	2.4 ± 0.2	2.2 ± 0.2	2.2 ± 0.2	2.1 ± 0.4	1.9 ± 0.3	1.9 ± 0.2	2.7 ± 0.2	0.3 ± 0.1

Table 2. Continued

Fall 2003

Data Type	Box Woodlot	Fernwood	Ft. Custer	Ives Rd.	Lux Arbor	Pinckney	Russ Forest	Shiawassee
Number of Quadrats Invaded	9	20	8	5	7	7	2	17
Total *A. petolata* Cover								
Rosette Cover (%)	2.0 ± 1.1	6.6 ± 1.6	3.6 ± 1.6	0.2 ± 0.1	1.3 ± 0.8	0.7 ± 0.5	0.1 ± 0.1	18.8 ± 6.4
Leaf Damage (% removed)	13.1 ± 3.7	2.4 ± 1	0.4 ± 0.1	0.1 ± 0.1	3.9 ± 0.8	0	0	1.1 ± 0.2
Windowpane Damage (%)	0	0	0	0	0	0	0	0
Edge Feeding Damage (%)	0.6 ± 0.1	0.4 ± 0.1	0	0	0	0	0	0
Holes Damage (%)	0.7 ± 0.1	0.6 ± 0.1	0.9 ± 0.1	0.2 ± 0.1	1.0 ± 0	0	0	1.0 ± 0
Browse Damage (%)	0	0	0	0	0	0	0	0
Disease Damage (%)	0	0	0	0	0	0	0	0
Other Damage (%)	0	0	0	0	0	0	0	0
Rosettes · $(0.5m^2)^{-1}$	3.7 ± 2.0	17.3 ± 4.2	8.4 ± 3.6	0.4 ± 0.2	1.8 ± 0.9	1.8 ± 0.9	0.4 ± 0.3	34.7 ± 10.7
Other Vegeation Cover (%)	11.6 ± 3.6	7.7 ± 1.8	2.9 ± 1.2	21.3 ± 3.9	8.3 ± 2.1	15.9 ± 2.7	18.0 ± 2.9	49.8 ± 7.1
Soil Cover (%)	3.4 ± 0.9	0.9 ± 0.2	0.6 ± 0.5	63.0 ± 6.1	28.8 ± 4.9	55.8 ± 6.3	1.4 ± 0.6	66.0 ± 5.1
Wood Cover (%)	7.8 ± 1.4	5.6 ± 1	7.2 ± 1.7	28.2 ± 5.8	17.7 ± 2.6	18.8 ± 4.1	11.1 ± 4.8	17.9 ± 2.8
Leaf Cover (%)	88.9 ± 1.6	93.3 ± 1	92.2 ± 1.7	8.8 ± 2.2	51.5 ± 5.5	25.5 ± 5.8	87.5 ± 4.8	16.1 ± 3.7
Rock Cover (%)	0	0.3 ± 0.2	0	0	2.1 ± 1.5	0	0	0.1 ± 0
Mean Litter Depth (cm)	4.1 ± 0.4	3.8 ± 0.3	3.7 ± 0.3	0.7 ± 0.2	2.1 ± 0.4	1.4 ± 0.3	3.4 ± 0.2	0.8 ± 0.2

Table 2. Continued

Fall 2004

Data Type	Box Woodlot	Fernwood	Ft. Custer	Ives Rd.	Lux Arbor	Pinckney	Russ Forest	Shiawassee
Number of Quadrats Invaded	17	13	3	18	15	14	13	5
Total *A. petolata* Cover								
Rosette Cover	4.0 ± 1.1	1.1 ± 0.3	0.3 ± 0.2	0.9 ± 0.2	18.9 ± 5.4	0.7 ± 0.2	1.5 ± 0.5	3.8 ± 3.0
Leaf Damage (% removed)	0.9 ± 0.3	1.5 ± 0.4	0.5 ± 0	1.1 ± 0.3	3.6 ± 1	2.9 ± 0.7	0.7 ± 0.2	1.3 ± 0.5
Windowpane Damage (%)	0	0	0	0	0	0	0	0
Edge Feeding Damage (%)	0.9 ± 0.1	0.8 ± 0.1	1.0 ± 0	0.8 ± 0.1	1.0 ± 0	0.8 ± 0.1	0.6 ± 0.1	0.4 ± 0.1
Holes Damage (%)	0.6 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.8 ± 0.1	1.0 ± 0	0.6 ± 0.1	0.8 ± 0.1	0.8 ± 0.1
Browse Damage (%)	0	0.1 ± 0.1	0	0	0	0	0	0
Disease Damage (%)	0	0	0	0	0.6 ± 0.1	0	0	0
Other Damage (%)	0	0	0	0	0	0	0	0
Rosettes · $(0.5m^2)^{-1}$	26.8 ± 5.9	9.6 ± 2.6	1.6 ± 1.0	14.0 ± 3.9	39.7 ± 10.7	7.3 ± 2.2	8.2 ± 2.4	11.1 ± 7.6
Other Vegeation Cover	5.1 ± 1.8	11.0 ± 3.9	34.5 ± 3.5	13.4 ± 2.6	6.7 ± 1.5	10.4 ± 2.8	15.6 ± 3.4	45.8 ± 8.9
Soil Cover	56.5 ± 5.5	7.3 ± 2.4	33.9 ± 4.7	34.1 ± 8	41.9 ± 7.3	36.3 ± 6.3	22.0 ± 5.3	51.7 ± 8.5
Wood Cover	22.4 ± 3.3	5.2 ± 1.2	8.2 ± 1.3	15.0 ± 2.8	8.1 ± 1.2	8.8 ± 1.9	8.7 ± 2.1	6.6 ± 1.6
Leaf Cover	21.2 ± 3.6	87.2 ± 2.9	58.0 ± 4.4	50.9 ± 8	48.2 ± 7.8	54.9 ± 6.2	69.3 ± 5.1	41.8 ± 8.6
Rock Cover	0	0.4 ± 0.2	0	0.1 ± 0.1	2.0 ± 1.3	0	0.0 ± 0	0
Mean Litter Depth (cm)	0.4 ± 0.1	1.7 ± 0.2	0.7 ± 0.1	1.0 ± 0.2	1.1 ± 0.3	1.0 ± 0.1	1.5 ± 0.2	0.8 ± 0.2

Table 2. Continued

Fall 2005

Data Type	Box Woodlot	Fernwood	Ft. Custer	Ives Rd.	Lux Arbor	Pinckney	Russ Forest	Shiawassee
Number of Quadrats Invaded	2	20	12	14	13	13	2	17
Total *A. petolata* Cover								
Rosette Cover (%)	0.1 ± 0.1	3.4 ± 0.8	1.9 ± 0.6	0.8 ± 0.1	2.9 ± 1.1	0.7 ± 0.1	0.1 ± 0.1	9.4 ± 2.8
Leaf Damage (% removed)	3.0 ± 0.6	6.7 ± 2.4	2.8 ± 0.9	7.6 ± 4.7	17.7 ± 5	7.4 ± 3	3.0 ± 0.6	5.5 ± 2.3
Windowpane Damage (%)	0	0.9 ± 0.1	0.6 ± 0.1	0.8 ± 0.1	0.5 ± 0.1	0.8 ± 0.1	0.5 ± 0.2	0.5 ± 0.1
Edge Feeding Damage (%)	0.5 ± 0.2	1.0 ± 0	0.7 ± 0.1	0.9 ± 0.1	1.0 ± 0	0.7 ± 0.1	0.5 ± 0.2	1.0 ± 0
Holes Damage (%)	0.5 ± 0.2	1.0 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.9 ± 0.1	0.5 ± 0.1	0.5 ± 0.2	1.0 ± 0
Browse Damage (%)	0	0	0	0	0	0	0	0
Disease Damage (%)	0	0	0	0	0	0	0	0.1 ± 0.1
Other Damage (%)	0	0	0	0	0	0	0	0
Rosettes · $(0.5m^2)^{-1}$	0.4 ± 0.3	38.9 ± 6.5	10.7 ± 3.3	5.0 ± 1.3	5.3 ± 2.1	4.3 ± 1.4	0.2 ± 0.1	40.2 ± 8.2
Other Vegeation Cover (%)	4.6 ± 1.7	5.1 ± 1	26.0 ± 3.3	6.7 ± 1.2	22.0 ± 6.5	9.7 ± 2.5	16.1 ± 3.2	53.8 ± 8
Soil Cover (%)	49.5 ± 4.5	3.4 ± 1.1	15.2 ± 4.4	31.5 ± 6.8	21.4 ± 5.7	20.6 ± 3.3	4.6 ± 1.1	77.9 ± 4.4
Wood Cover (%)	13.0 ± 1.8	4.8 ± 0.9	7.2 ± 1.7	12.7 ± 2.1	16.3 ± 3.2	7.0 ± 1.5	6.0 ± 0.9	8.9 ± 1.4
Leaf Cover (%)	37.5 ± 4.3	91.6 ± 1.4	77.7 ± 4.6	55.8 ± 5.9	60.9 ± 6.8	69.0 ± 4.9	89.5 ± 1.4	13.1 ± 3.8
Rock Cover (%)	0.1 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	1.5 ± 1	3.5 ± 3.4	0	0.1 ± 0.1
Mean Litter Depth (cm)	0.5 ± 0.1	2.4 ± 0.2	1.4 ± 0.2	2.2 ± 0.4	1.7 ± 0.3	1.6 ± 0.2	2.1 ± 0.2	0.2 ± 0.1

Table 3. Number of sampling quadrats at each site where live *A. petiolata* was observed during each spring sampling period and percent change over time. Mean values are ± 1 SE. Means for percent change and relative percent change do not include data from Fernwood which was fully invaded during all years.

Year	Box Woodlot	Fernwood	Ft. Custer	Ives Rd.	Lux Arbor	Pinckney	Russ Forest	Shiawassee	Mean
Invaded Quadrats									
2003	16	20	7	18	9	10	9	14	13 ± 1.7
2004	18	20	11	17	16	16	14	15	16 ± 1.0
2005	19	20	11	19	15	20	13	18	17 ± 1.2
Relative Change (%)[a]									
2003 → 2004	12.5	0.0	57.1	-5.6	77.8	60.0	55.6	7.1	37.8 ± 12.2
2004 → 2005	5.6	0.0	0.0	11.8	-6.3	25.0	-7.1	20.0	7.0 ± 4.7
2003 → 2005	18.8	0.0	57.1	5.6	66.7	100.0	44.4	28.6	45.9 ± 12.1
Change (%)[b]									
2003 → 2004	50.0	0.0	30.8	-50.0	63.6	60.0	45.5	16.7	30.9 ± 14.8
2004 → 2005	50.0	0.0	0.0	66.7	-25.0	100.0	-16.7	60.0	33.6 ± 18.0
2003 → 2005	75.0	0.0	30.8	50.0	54.5	100.0	36.4	66.7	59.0 ± 9.0

[a] Relative percent change indicates the change in the number of invaded quadrats during the time interval indicated relative to the number invaded at the start of the interval.

[b] Percent change is the percent of initially uninvaded quadrats that were invaded during the indicated time interval.

Table 4. Univariate repeated measures ANOVA of the number of quadrats invaded by *A. petiolata* over time within sites. Test excludes the Fernwood site where initial conditions prevented estimation of spread.

Source	SS	*df*	MS	*F*	*P*
Year	79.2381	2	39.6190	11.8575	0.0014
Error	40.0952	12	3.3413		

Table 5. Dunn-Sidak adjusted comparisons of the number of invaded quadrats per site between years.

Within Subject Factor Comparing:	Mean Difference Between Levels	Std Error Of Difference	*P*	Lower 95% CI	Upper 95% CI
2003 ↔ 2004	-3.4286	1.088	0.0582	-6.9904	0.1333
2004 ↔ 2005	-1.1429	0.7377	0.4330	-3.558	1.2723
2003 ↔ 2005	-4.5714	1.0659	0.0154	-8.0609	-1.082

Figure 2. Approximate known distribution of *A. petiolata* within Michigan's lower peninsula (shaded counties) (Voss 1985, J. Evans and D. Landis pers. obs) and locations of study sites (stars).

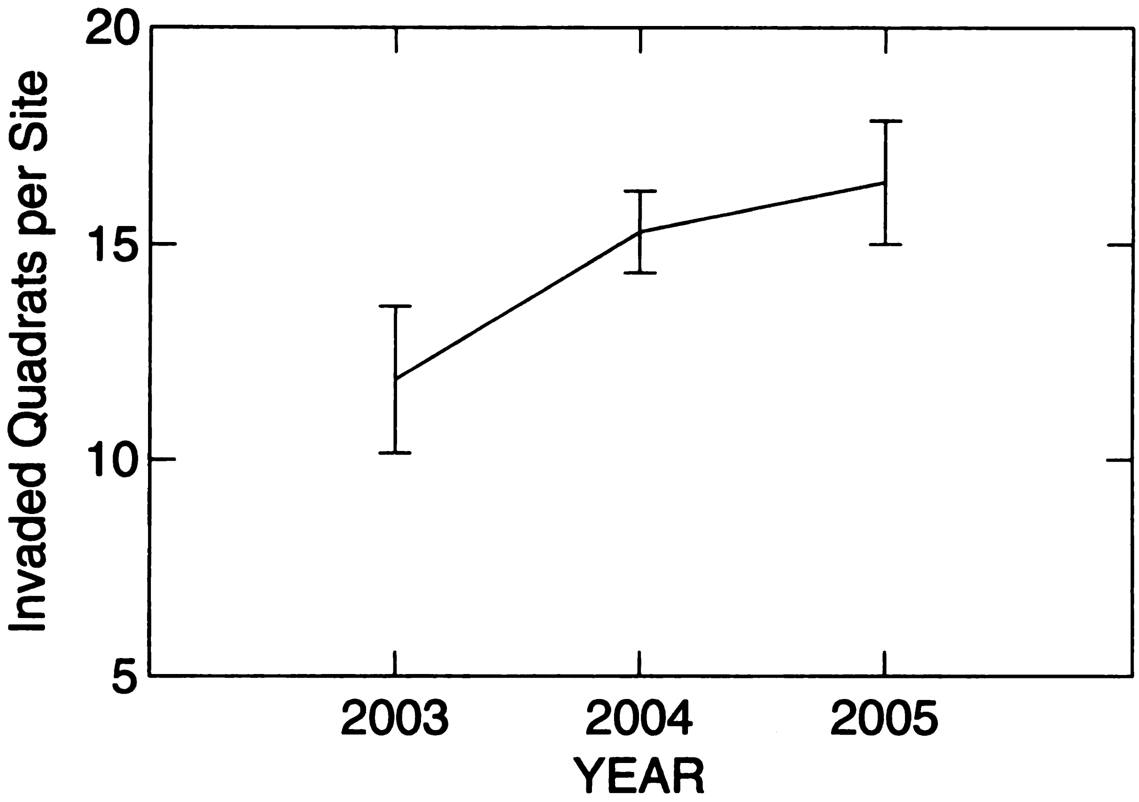

Figure 3. Mean number of sampling quadrats per site (n = 20) where live *A. petiolata* plants were observed. Fernwood data are not included because all quadrats were invaded there during all three years.

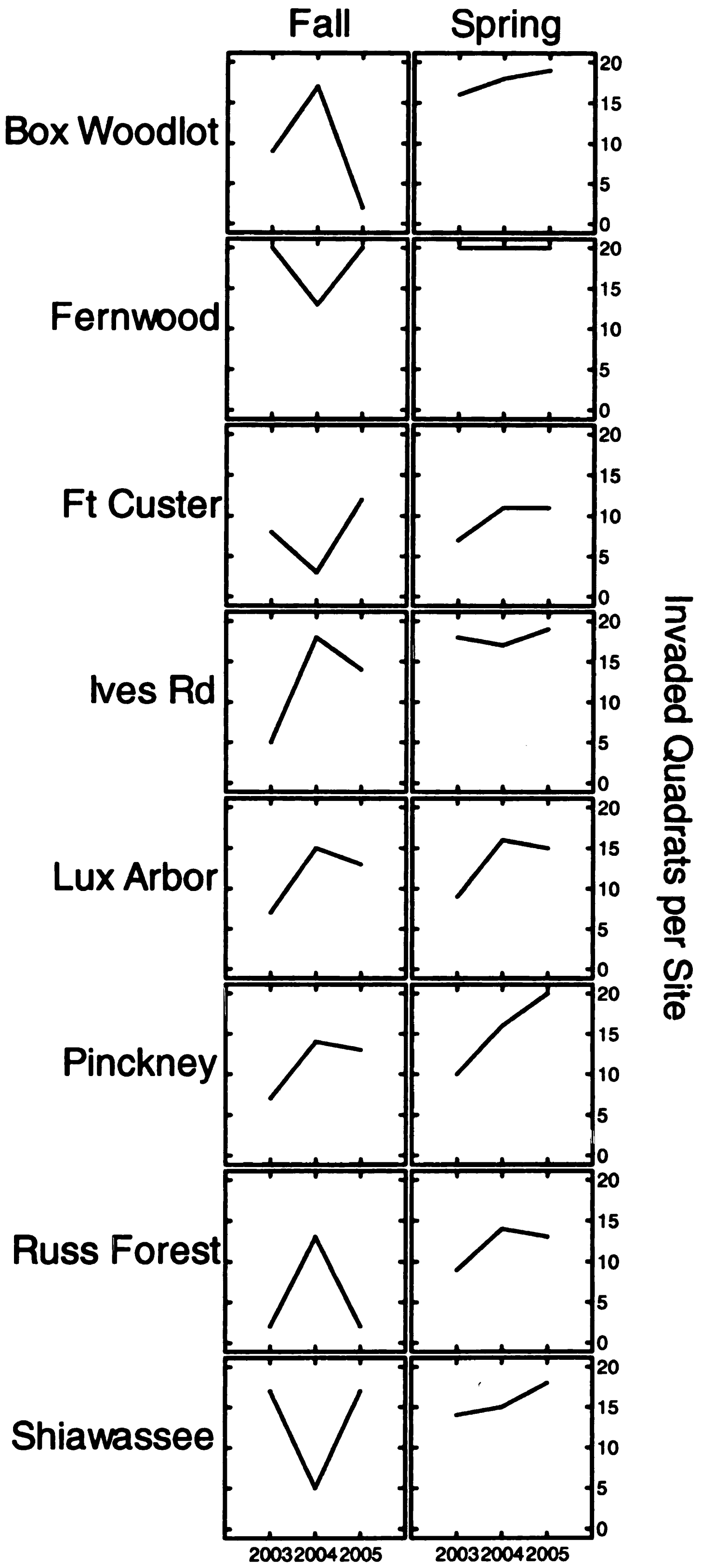

Figure 4. The number of sampling quadrats containing live *A. petiolata* during sampling has increased since 2003 at most sites during spring and fall.

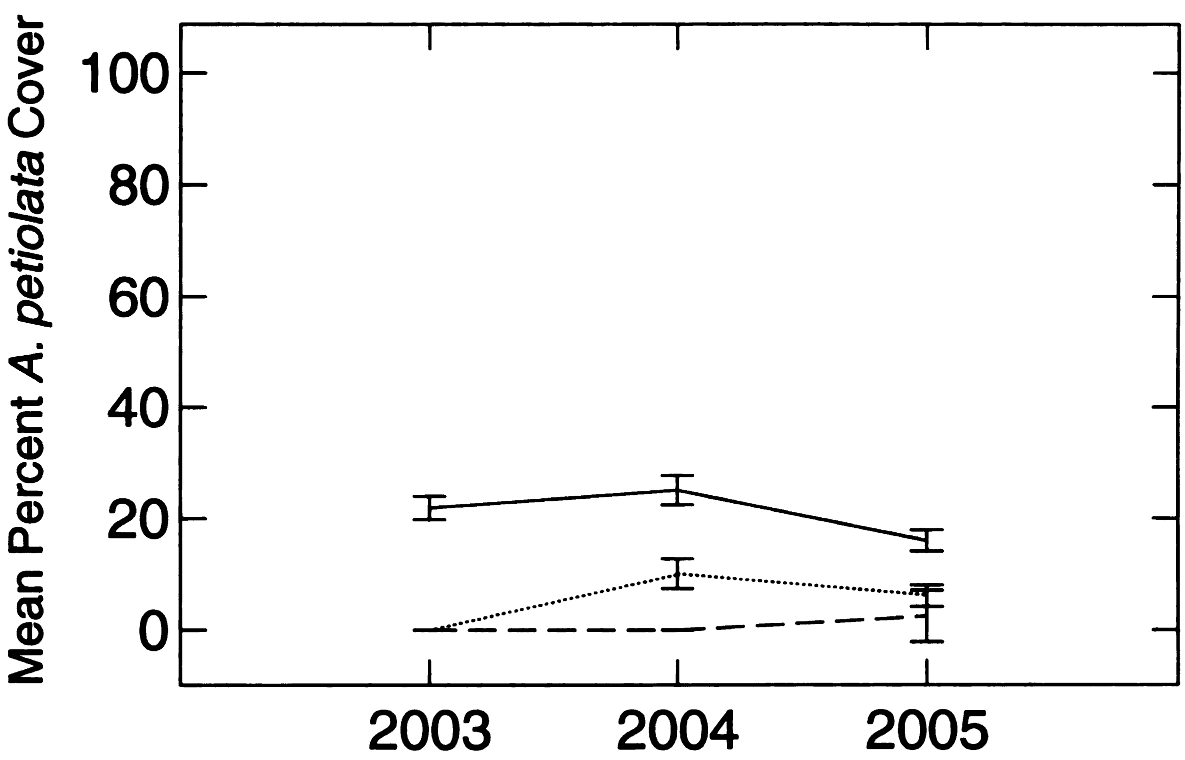

Figure 5. Mean percent *A. petiolata* cover per quadrat from all quadrats during each sampling period. Solid line shows quadrats that were invaded in 2003, dotted line shows quadrats that were not invaded in 2003 but became invaded in 2004, and the dashed line shows quadrats that became invaded in 2005. Cover estimates are from spring only.

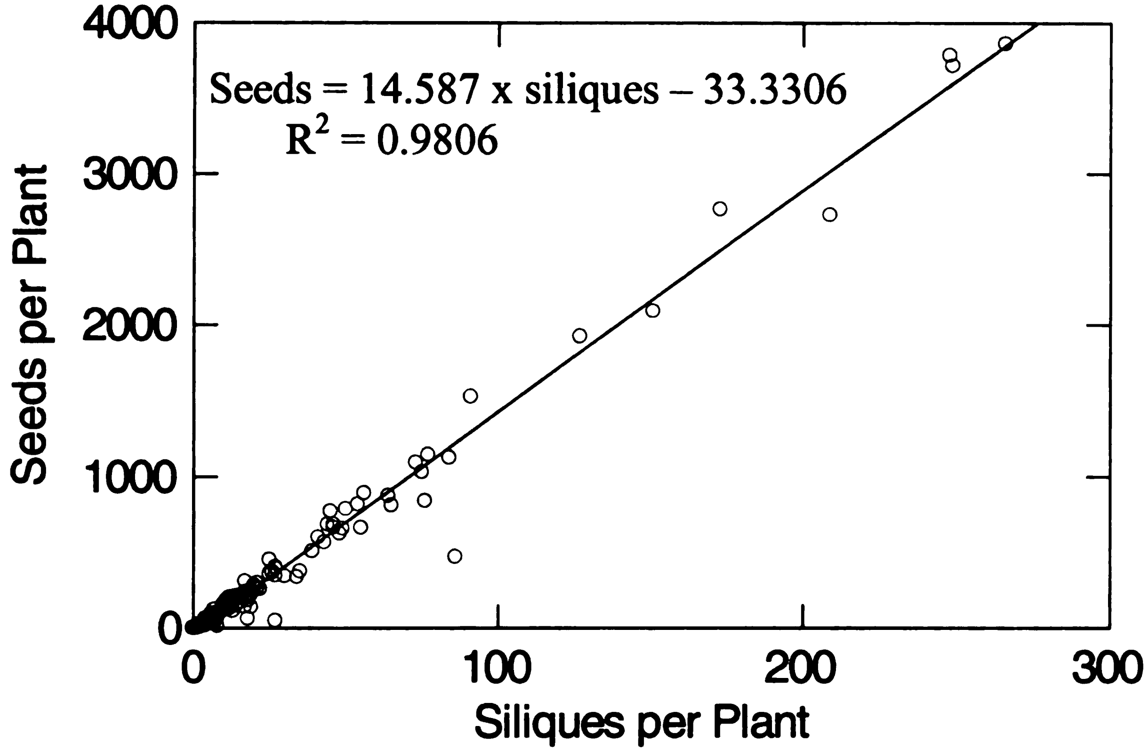

Figure 6. Regression used to estimate fecundity of *A. petiolata* plants. Plants used in this analysis were collected at multiple locations across southern Michigan.

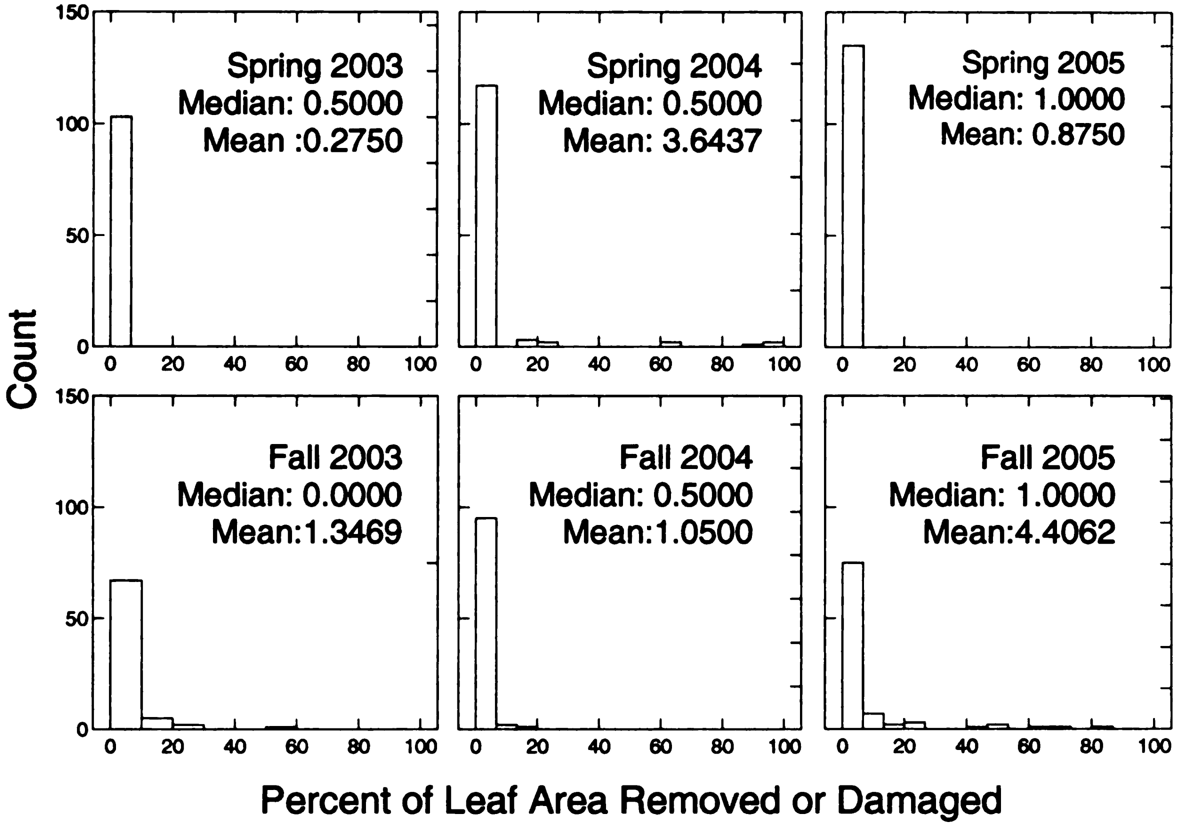

Figure 7. Frequency distribution of damage to *A. petiolata* foliage during each sampling season. Damage was frequent but was rarely extensive.

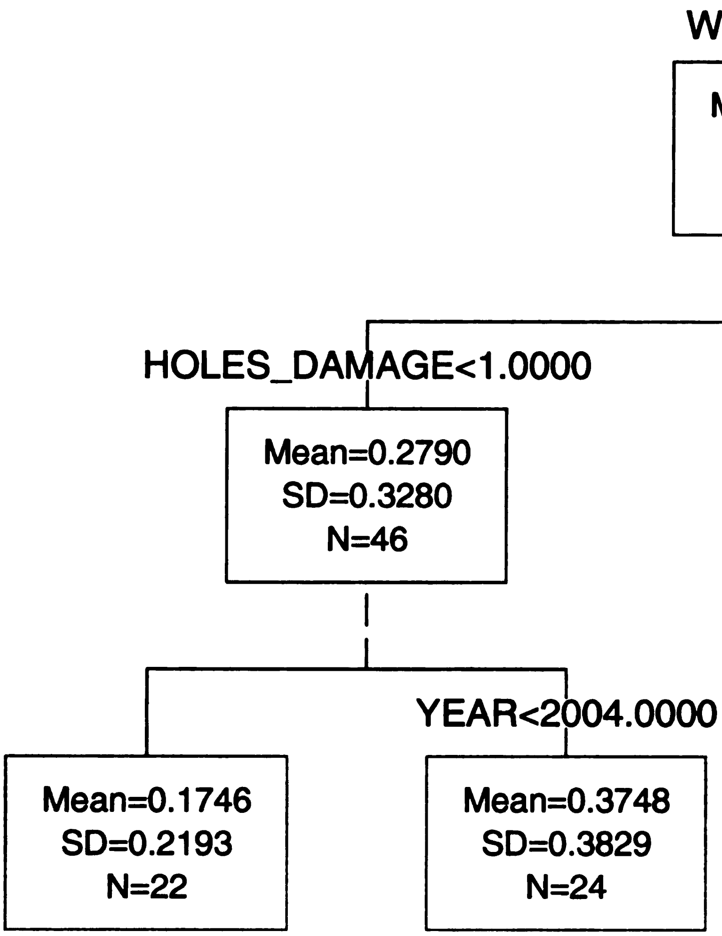

Figure 8. The relationship between overwintering survival and damage to *A. petiolata*, year, site, and species richness is not significant. When the splitting criteria are relaxed and site is dropped as a predictor, overwintering survival in quadrats with holes-damage to *A. petiolata* was insignificantly higher than in those without such damage. (PRE for overall model = 0.0852). Within quadrats that did not have holes-damage to *A. petiolata* plants in fall, overwintering survival was insignificantly higher in the winter of 2004 – 2005 than 2003 – 2004. Dashed lines in figure indicate statistically insignificant splits.

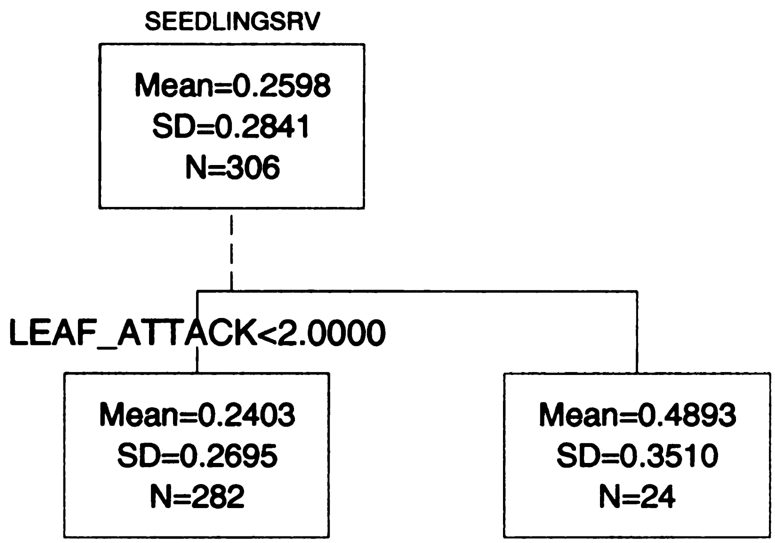

Figure 9. When site is not included as a predictor of fecundity, the 24 quadrats in which *A. petiolata* sustained greater than or equal to 2% damage to leaves had insignificantly higher seedling survival than those with less than 2% damage. Overall PRE fit = 0.0557. Dashed line indicates statistically insignificant split.

Chapter 3

DYNAMICS OF *ALLIARIA PETIOLATA* (GARLIC MUSTARD) INVASIONS IN SOUTHERN MICHIGAN FORESTS

Jeffrey Adam Evans

ABSTRACT

Invasive species are frequently cited a among the greatest threats to global biodiversity, although quantifying such impacts is challenging. Authors have variously argued that invasions have strong or weak impacts on native communities, and that the relationship between exotic and native plant species richness or abundance is positive (biotic enhancement), negative (biotic resistance), or insignificant. Others have asserted that the relationships are simply a function of the scale at which studies are conducted. Those who favor biotic resistance cite resource competition with native species and stochastic survival and mortality as the primary mechanisms limiting or propelling invasions. Proponents of biotic enhancement show that native and exotic species richness are often positively correlated and covary with extrinsic environmental factors such as climate, resource inputs, and geological features, thus proving that exotic and native species are functionally similar. As the scale of comparison increases from local to regional, the relationship of native to exotic diversity typically changes from negative to positive as intrinsic factors that structure processes at the quadrat scale are overwhelmed by extrinsic factors that dominate local to regional processes. While the native and exotic species richness of the sites were positively correlated ($P = 0.0002$), the relationship between native species richness and *A. petiolata* abundance within sites varied as a function of site species richness ($P = 0.0165$) from insignificant at species-poor sites to negative at species-rich sites. Most interestingly, I found that the relationship of local scale native species richness to *A. petiolata* presence or absence reversed from species rich to species poor sites ($P = 0.0087$). In species-rich sites where resource availability to

plants is presumed to be greatest, quadrats with *A. petiolata* had significantly lower species richness, implying that biotic resistance may be limiting establishment there. Alternately, at species-poor sites where resource availability is expected to be limiting, quadrats with *A. petiolata* had significantly higher species richness. This suggests that neither biotic resistance nor enhancement alone sufficiently explains *A. petiolata*'s invasion processes. Rather, they serve as endpoints along a continuum of tradeoffs between resource competition and stress tolerance. This enriches current models that have only found such reversals across gradients of scale.

INTRODUCTION

Biological invasions have been implicated in the disruption and alteration of many biological systems through a broad range of mechanisms. Invaders compete with natives for resources (Mack et al. 2000), alter habitat structure (e.g. Benoit and Askins 1999, Bohlen et al. 2004, Hale et al. 2005) and chemistry (e.g. Callaway and Aschehoug 2000, Bais et al. 2003), and sometimes alter successional processes via changes to soil fungal communities and fire intensity or frequencies (e.g. D'Antonio and Vitousek 1992, Stinson et al. 2005). These changes to both natural and managed systems have significant implications for biotic communities (Wilcove et al. 1998) and substantial associated economic costs (U.S. Congress 1993, Pimentel et al. 2000, Pimentel 2005). Understanding whether communities differ in their susceptibility to being invaded and whether invaders will negatively impact native communities if they become established is of key concern to both researchers and managers alike. But predictions of the functional and numerical relationships between invading species and the composition of invaded communities vary widely.

BIOTIC RESISTANCE HYPOTHESES

Much of the discussion on invasibility has centered on the biotic resistance hypothesis which predicts that species-rich communities should be more resistant to invasion than species-poor communities (termed 'ecological resistance' by Elton 1958). This expectation that diversity limits invasions is explained in part by niche partitioning and mass effects and has been supported empirically in some systems (Knops et al. 1999, Levine and D'Antonio 1999, Stachowicz et al. 1999, Naeem et al. 2000). Tilman's stochastic niche model (Tilman 2004) similarly predicts that invasion probability decreases exponentially as species richness increases by incorporating both stochastic (e.g. Hubbell 2001) and competitive (e.g. Tilman 1976) elements from earlier models. This outcome is predicted because (1) different species require different but overlapping resources, (2) invader propagule dispersal is influenced by stochastic processes (i.e. the movements of floodwaters, rodents, bird excrement, etc. dictate where propagules are deposited), (3) propagules can only become established where the resources they require are available, (4) established species use resources and make them unavailable to invaders, and (5) the more established species that are present and using resources, the lower the probability is of an invader's propagule arriving exactly where its required resources are present and unused. If the new species survives these largely stochastic dispersal obstacles, the invader will only establish if its R* (Tilman 1976, 2004) is equal to or lower than those of its competitors. That is, the invader must be able to reduce the availability of a limiting resource below the level required by competing species. If it does, it will then displace any competing species that are limited by that resource. Tilman's (2004) predictions are not radically different from those of other biotic resistance models, but the concert of stochasticity and competitive interactions in a single model is more biologically plausible than either element operating alone.

BIOTIC ENHANCEMENT HYPOTHESES (THE RICH GET RICHER)

Other studies contradict the expected negative relationship between native and exotic species richness or cover (Levine and D'Antonio 1999, Stohlgren et al. 1999a, Stohlgren et al. 2002, Stohlgren et al. 2003, Stohlgren et al. 2005). This pattern suggests that invasive species are functionally equivalent to native species in their resource requirements and that resource rich habitats which support large numbers of native species should be highly invasible (e.g. Stohlgren et al. 2003). Stohlgren (1999a) and Stohlgren et al. (2003) have argued that the negative relationship "paradigm" is supported primarily by studies conducted at the 1-m^2 scale or smaller and even then only in some systems. At increasingly larger spatial scales this negative correlation typically breaks down such that the overall relationship between native and non-native species richness or cover is positive, i.e. "the rich get richer" (Stohlgren et al. 2003). Shea and Chesson (2002) suggest that conflicting patterns of native versus exotic abundance observed at different spatial scales may stem from variation in extrinsic factors such as climate, geology, and rates of system-wide resource inputs at larger scales which overwhelm the interspecific interactions that dominate local or plot-scale processes. Empirical evidence from croftonweed (*Eupatorium adenophorum*) invasion in southwest China is supportive of this proposal and, additionally, indicates that the relationship between native diversity and invasion susceptibility also changes with time since invasion (Lu and Ma 2005). This implies that the sampling scale may affect the significance or direction of any conclusions drawn in studies of invasive species impacts on native communities.

These conclusions are not entirely explanatory. Stohlgren et al. (1998, 1999a, 1999b, 2001, 2002) found positive relationships between the absolute cover or biomass of native and exotic species at many spatial scales. However, analysis of the relative abundances of species (calculated from the data in Stohlgren et al.'s works cited above) shows that there is either no relationship or a negative relationship between native species richness and exotic species relative cover at spatial scales from 1-4000 m^2 (Lundholm and Larson 2004), which is exactly the opposite of Stohlgren et al.'s general conclusions.

The positive relationships observed from studies of absolute native and exotic cover indicate that both groups of species respond broadly to the same environmental conditions, but the neutral to negative relationship of relative exotic cover to native richness indicates first that absolute abundance or number of invaders should not be equated with dominance by them, and second that species rich communities may have some ability to resist invasions (Lundholm and Larson 2004). Thus, although biotic resistance is not predicted to prevent invasion from occurring, it has been shown to play a role in lowering establishment probability, rates of spread and impacts (Levine et al. 2004).

INTERPRETING IMPACTS OF INVASIONS

Quantifying the impacts of invasive species on indigenous communities can be difficult. Often there is no pre-invasion dataset to compare with the post-invasion community or the impacts are ambiguous (*e.g.* Koenig 2003). In unmanipulated natural systems there may be strong correlations between invading species and patterns of native species abundance, but causality cannot be assigned. Causal relations might, however, be inferred where the biology of the invader is well understood. For example, the invasive weed *Centaurea maculosa* DC. (Asteraceae) has been widely studied and shown to interact with native plant assemblages in part via allelopathic root exudates (Bais et al. 2003). Kedzie-Webb et al. (2001) revealed significant negative relationships between *C. maculosa* abundance and native grass abundance, richness, and diversity, but could not conclude whether *C. maculosa* caused reduction of native grass richness and abundance or whether it invaded and become abundant in areas that were already lower in native species richness. There is value in identifying these patterns in natural communities, though, as they serve to guide future research efforts that can distinguish cause from effect. Additionally, analyses of natural systems are not subject to the criticism generally directed at studies of artificial communities and may shed light on true natural associations between species.

Study Species

Alliaria petiolata (M. Bieb) Cavara and Grande (garlic mustard) is an invasive weed of European origin. First recorded on Long Island, New York in 1868 (Nuzzo 1993), it is now widely distributed and invasive in North America (Nuzzo 1993, 2000). It is notable among invaders in its ability to penetrate high quality forest understories as well as disturbed areas. Previous studies indicate that *A. petiolata* growth rates and fecundity are positively correlated with light availability (Meekins and McCarthy 2000) and that *A. petiolata* populations respond positively to the formation of canopy gaps (Luken et al. 1997, Webb et al. 2001). *Alliaria petiolata* interactions with native species may be mediated through soil communities. Ongoing research suggests that exotic earthworms which increase litter cycling rates may be correlated with increased *A. petiolata* abundance (Maerz et al. 2002, C.M. Hale, Univ. of Minnesota, Duluth, pers. comm., 2003, Bohlen et al. 2004, Hale et al. 2005). Additionally, *A. petiolata* is amycorrhizal and has allelopathic properties that disrupt associations between native plants and their arbuscular mycorrhizal fungi (ABF) (Roberts and Anderson 2001, Stinson et al. 2005, Wolfe and Klironomos 2005) and directly suppress germination of sympatric species (Roberts and Anderson 2001, Prati and Bossdorf 2004).

COMMUNITY RESPONSE TO INVASION AND CONTROL EFFORTS

Land managers in many systems report negative responses of native plant communities to increasing abundance of *A. petiolata.* Anecdotal evidence of this type is widespread, though few studies have addressed this assertion. McCarthy (1997) concluded that diversity increased as *A. petiolata* was experimentally removed, but the sign of the effect he observed changed multiple times over the course of his study. Recent findings demonstrating that the impacts of *A. petiolata* on ABF persist for years after *A. petiolata* extirpation (Stinson et al. 2005) suggest that McCarthy's study plots were likely still subject to the legacy effects of *A. petiolata* even after it had been removed. Because of the difficulty in interpreting the lingering effects of an invader after its removal, an alternative approach may be to observe *A. petiolata* as it invades new areas. One can then assess whether communities that are invaded differ from those that remain uninvaded from the outset, and whether communities that become invaded diverge from their uninvaded counterparts.

There is substantial interest in developing effective control strategies for naturalized *A. petiolata* populations in North America. Conventional control methods such as pulling, cutting, spraying, and burning are ineffective on all but the smallest infestations (Nuzzo 1991, 1994, Nuzzo et al. 1996). Current research efforts are therefore focused on classical biological control and host specificity testing of European insect natural enemies (Blossey et al. 2001, Hinz and Gerber 2005). My study was designed to establish benchmark, pre-release data at multiple *A. petiolata* invaded locations to support and allow evaluation of the effectiveness of biological control efforts if they are implemented in the future. Pre-release baseline community data such as these are rich with ecological information and can provide added insight into the processes directing *A.*

petiolata invasions in our area. Because no manipulations were performed in this study all interpretations are strictly correlative. However, no other datasets of *A. petiolata* populations and community dynamics that I know of exist with this scale of replication. Thus, correlative analysis is appropriate in this case as it may allow quantitative support for the phenomena that many have casually described.

OBJECTIVES

From April, 2003 through October, 2005 I followed the progression of invasion by naturalized *A. petiolata* populations at eight sites in the southern Lower Peninsula of Michigan. The objectives of this study were to (1) characterize the plant species assemblages at these eight locations prior to the introduction of biological control agents, (2) identify potential impacts of *A. petiolata* invasions on these communities, and (3) to evaluate patterns of *A. petiolata* invasions within the broader framework of plant invasion theory.

METHODS AND MATERIALS

SITE SELECTION:

I utilized eight previously established study sites within *A. petiolata*'s primary range in Michigan's southern Lower Peninsula (Landis et al. 2004). Criteria for site selection included (1) forested lands > 2 ha in extent, (2) under state, federal, or other long-term conservation management, (3) on which *A. petiolata* populations have been established for at least four years, and (4) with protection from future disturbance or *A. petiolata* management for at least ten years. In spring of 2003 10 permanent 0.5 m^2

sampling quadrats (0.5 x 1 m) were marked along each of two parallel, 100 m long transects spaced 10 m apart at seven sites and along one 200 m long transect with 20 sampling quadrats at the eight site (Russ Forest) for a total or 20 quadrats per site, and GPS coordinates were recorded for each site. Transects traversed the *A. petiolata* invasion front where possible. This was done to allow us to measure spatial spread of *A. petiolata* populations within sites. At one site (Fernwood) this was not possible, and all 20 quadrats there contained *A. petiolata* from the outset of the study. Site inventories included data on forest type (MNFI 2003) and maturity (diameter at breast height of principal overstory trees), and overall plant community composition. Sites are described in greater detail in Chapter 2. Accurate records of species composition were not kept at these sites before the initiation of this study. It is therefore not possible to determine exactly how long *A. petiolata* had been present at any of the sites prior to 2003, although the extent of the invasions and anecdotal evidence from managers indicated that they met the criteria listed above.

SAMPLING METHODS:

I collected data on *A. petiolata* distribution and abundance based on a nationally standardized protocol developed for pre-biocontrol-release monitoring of *A. petiolata* populations (Nuzzo and Blossey unpublished). In spring (June) and fall of (Sept. – Nov.) of 2003 – 2005 I visited each site and recorded vegetation percent-cover from each quadrat including *A. petiolata*, and non-A. *petiolata* vegetation by species. Specimens of species that were not identifiable were collected near the quadrats for later identification. Estimates of total cover often exceeded 100% because each species' cover was estimated separately and the layers of vegetation frequently overlapped.

Analyses of Data

Site Overviews and Characterization

To characterize the sites I compiled inventories of all ground layer vascular plant species (up to one meter height) for each site from the six combined sampling dates. I used the Michigan Natural Features Inventory (MNFI) community types (MNFI 2003) and calculated the negative logarithm of Simpson's diversity index (-ln*D*), the Berger-Parker index of dominance (*d*), and Floristic Quality Assessment indices (described below) to characterize the ground-layer plant species composition and distribution at the eight study sites. All biodiversity indices were calculated using formulas in Magurran (2004) with the exception of the Floristic Quality Assessment indices (Taft et al. 1997, Herman et al. 2001). Metrics of diversity which include *A. petiolata*-data become overwhelmed at high *A. petiolata* abundances while information from the residual community is forced into the tails of the species distribution. Therefore, I analyzed indices calculated for the residual community without *A. petiolata* except where noted. Calculations in which *A. petiolata* data were included are subscripted with the letters "GM" (for Garlic Mustard) to distinguish them from those that were not. Indices calculated from native species data only are subscripted with the letter "N" (for Native). For analyses of transect-scale patterns indices were calculated from the summed data from all quadrats within each site (20 quadrats x 0.5 m^2 = 10 m^2). Only first year plants were censused during fall sampling because second year plants had already senesced. Therefore, only spring data were used in my analyses.

Effects of Deer

Previous studies have shown that browsing by white-tailed deer [*Odocoileus virginianus* (Boddaert)] exacerbates the negative impacts of *A. petiolata* invasions on native plant communities (Kalisz et al. 2003). I evaluated the relationship between site native species richness and county deer density estimates from the Michigan Department of Natural Resources (MDNR 2006) using Spearman rank correlations with PROC CORR in SAS version 8.2 (SAS Institute 2001) to identify any potentially confounding effects of deer density on native species and *A. petiolata* spread.

Metrics of Diversity

Simpson's Diversity Index (-lnD)

Simpson's diversity index (D) is a measure of the probability that any two individuals chosen randomly from a sample belong to the same species. Simpson's D is weighed significantly towards the most abundant species but is not very sensitive to differences in species richness which makes it an appropriate measure for comparisons between sites with different numbers of species (Magurran 2004). In this analysis, percent cover was used in the calculations as the measure of abundance. The negative logarithm of Simpson's D ($-\ln D$) ranges from 0 to $+\infty$, with higher values representing increasing diversity, and is recommended over the commonly-used $1/D$ for its improved variance properties and similar ease of interpretation (Magurran 2004 and references therein).

Berger-Parker Index of Dominance (d)

The Berger-Parker index of dominance (*d*) is a measure of the relative abundance of the most abundant species. Values of *d* range from $1/S$ (perfect evenness) to 1 (monoculture).

Floristic Quality Assessment

Floristic Quality Assessment is an established analytical system for interpreting the overall integrity of plant communities based on the conservativeness of the plant species present (Taft et al. 1997, Herman et al. 2001). All species native to the study range are assigned a coefficient of conservatism (*C*) ranging from 0 – 10. Common native species that show no specific affinity to undisturbed habitats are assigned a *C* of 0, while rare native species that are only found in the highest quality undisturbed natural areas are assigned a *C* of 10. Non-native species (also referred to as adventive) are given a *C* of 0, as they do not ad to the quality a site's flora. Each site inventory is summarized by its mean *C* value ($\overline{C}$) and Floristic Quality Index (*FQI*), which is calculated as:

$$FQI = \overline{C}\sqrt{S}$$

where *S* is the number of species in the sample and $\overline{C}$ is the mean coefficient of conservatism for the sample. The *FQI* is a weighted metric that allows for comparison between samples of different species richness (i.e. between sites).

I conducted FQA analyses using the Floristic Quality Analysis computer program and Michigan Flora database (Wilhelm and Masters 1999, Herman et al. 2001). Species lists from the six sampling periods were combined to create species inventories for each site and calculate FQA statistics for overall site compositions using the FQA "inventory" program. Additionally, FQA statistics were calculated for each site during each sampling period using the FQA "transect" program, which weights calculations of FQA statistics by species frequency and abundance. The frequency (number of quadrats x $site^{-1}$), relative frequency (number of observations x total number of $observations^{-1}$), cover (sum of cover for all quadrats within site), relative cover, and relative importance value (*RIV*) were calculated for each species. *RIV* is calculated as one-half the sum of the relative frequency and relative cover for each species.

The site characterizations are summarized by Michigan natural community type, (MNFI 2003), known disturbances, native and total species richness, FQA statistics, Simpson's –ln*D*, the Berger-Parker index of dominance (*d*), and both seasonal and overall species inventories.

Site-Level Diversity Comparisons

Native vs. Exotic Species Richness

The most robust prediction of Stohlgren et al.'s (2003) "rich get richer" model is that native and exotic species richness are positively correlated at larger spatial scales. I tested this with a Spearman rank correlation analysis of site exotic species richness and site native species richness using the site inventory data (SAS Institute 2001). Following this, I considered patterns of diversity and evenness between sites and whether anthropogenic or natural sites features logically correspond with them.

Differences Between Sites

I used Kolmogorov-Smirnov two-sample tests to compare patterns of species abundance distributions between sites. The Kolmogorov-Smirnov two-sample test is used to compare two sets of paired data (paired by rank number) and evaluate the significance of the maximum difference within pairs (Magurran 2004). With an experiment-wise error rate of $\alpha = 0.5$, the Dunn-Sidak correction for multiple comparisons (Gotelli and Ellison 2004) between the 28 possible pairs of sites within each season was $\alpha' = 0.0018$. Because the test can only compare two distributions at a time, I created two summary distributions for each site. In the first I ranked species separately within each quadrat and then calculated the mean relative abundance of each rank within the site. In the second distribution I summed the abundances of each species within each site across the 20 replicate quadrats and then ranked their relative abundances. The mean distribution characterizes the relative abundances of species at the quadrat scale (0.5 m^2) which is closer to the scale at which inter- and intraspecific interactions occur, while the summed distribution shows patterns at the scale of the transects (10 m^2). In the former, the species' identities are not tied to their ranks, whereas they are in the latter distribution. Kolmogorov-Smirnov tests were run using cumulative relative species abundances rather than absolute abundances to allow comparisons between sites with different numbers of species and total amounts of vegetation cover.

Alliaria petiolata Impacts and Invasion Processes

I evaluated the potential impacts of *A. petiolata* invasions on native communities and the possible roles of biotic resistance and facilitation in regulating invasions. This was a two step process in which I first analyzed patterns of invasion and diversity within sites by relating patterns of native species richness to *A. petiolata* presence or abundance at the quadrat scale. To test whether invasion patterns within sites are correlated with site-level patterns of diversity, I then related these quadrat-scale findings to the native species richness of the sites.

Interaction of Site Species Richness and A. petiolata Presence

To test the hypothesis that *A. petiolata* presence is negatively correlated with native species richness at the site level, I used a two way factorial GLM with *A. petiolata* presence or absence and site as main effects and tested for the significance of the interaction term (SYSTAT Inc. 2004) for each year. A significant interaction between site and *A. petiolata* presence would indicate that *A. petiolata* is related to native species richness differently at sites with different properties. The Fernwood site was completely invaded during all years, and Pinckney was completely invaded in 2005, so these sites were dropped form the analyses of those years, respectively.

Quadrat-Scale Correlations

Many studies have found negative correlations between native and exotic diversity or cover at small spatial scales (Shea and Chesson 2002). I tested the relationship between native species richness and *A. petiolata* abundance within sites using Spearman rank correlations constructed from quadrat data for each spring sampling date. I tested these relationships with both absolute (mean *A. petiolata* percent cover) and relative *A. petiolata* cover successively because of possible discrepancies between these two metrics (Lundholm and Larson 2004).

Linking Invasion Processes across Scales

To evaluate the hypothesis that diversity and *A. petiolata* abundance within sites are related as a function of site characteristics, I used Spearman rank correlations to test the associations between the quadrat scale correlation coefficients (from the preceding section) and native species richness from each site. Significant findings in these relationships would suggest that patterns of *A. petiolata* invasion vary as a function of intrinsic site or community characteristics and could be generalized to explain broader patterns of invasibility.

Predicting Invasion Probability

Observation of patterns of new invasions in natural communities is a strong correlative test of biotic resistance. Fifty-seven sampling quadrats distributed across seven of the eight sites were located where *A. petiolata* had not yet invaded in 2003. By spring of 2004 some of these quadrats had become invaded by *A. petiolata*. The data collected from these 57 quadrats afforded opportunities to explore hypotheses about the *A. petiolata* invasion process in Southern Michigan. Specifically, I hypothesized that increasing species richness would be predictive of a decreasing probability of invasion by *A. petiolata*.

Within the 57 uninvaded quadrats, I modeled the probability of a quadrat becoming invaded with a logistic regression using the presence or absence of *A. petiolata* in 2004 as a binomial response variable and either native or total species richness as a continuous predictor variable. In this model, the presence of *A. petiolata* in 2004 represented an "event" outcome while the absence of *A. petiolata* in 2004 was a "non-event". I hypothesized that, at the quadrat level, invasion probability would be negatively related to native or total species richness, which would lend support to the general biotic resistance framework. I first tested for significant blocking effects of site and then pooled the 57 observations. I used PROC LOGISTIC (SAS Institute 2001) to carry out a series of logistic regressions which were then evaluated based on multiple criteria (Peng and So 1998, Peng et al. 2002, Peng and So 2002).

Overall fit was evaluated by comparing the logistic models with intercept-only (null) models using Likelihood ratio, Score, and Wald tests. If the logistic model had greater predictive power than the null model, Wald's χ^2 tests were then used to test the significance of individual predictor parameters. The fit of the model to the data was evaluated with several goodness-of-fit tests. The Hosmer-Lemeshow statistic is an inferential Pearson's χ^2 statistic that tests the null hypothesis that the model is a good fit to the data. The model is said to fit the data well when $P > \alpha$. Additionally four measures of association are reported: Kendall's Tau-*a*, Goodman-Kruskal's Gamma, Somers's D_{yx}, and the *c* statistic. Each of these estimates the degree of association between the outcome and the predictor. Kendall's tau-*a* is a rank-order correlation coefficient that does not adjust for ties. The Gamma and Somer's D_{yx} estimate the percent reduction in prediction errors made using the logistic model versus chance alone. (a Gamma of 0.25 would thus mean a 25% reduction in predictive error using a given model). D_{yx} may represent an improvement over Gamma in that independent and dependent variables can be specified.

Finally, the *c* statistic is the proportion of paired observations with different outcomes (i.e. one quadrat is invaded while one is not) for which the model correctly predicts a higher probability for "event" observations (invaded) than the probability of "non-event" observations (not invaded) (Peng et al. 2002). For example, a *c* of 0.65 would mean that for all pairs of observations that had different invasion outcomes, the model correctly predicts the quadrat that became invaded 65% of the time. Values of *c* range from 0.5 to 1.0.

RESULTS AND DISCUSSION

Our ability to differentiate plant species improved substantially between 2003 and 2004 and again between 2004 and 2005. We recorded 95, 116, and 131 species in 2003, 2004, and 2005 respectively with 146 individual species observed during all three years. Thus, species data from 2003 (not collected by the author) are not reasonably comparable to data from other years, and I have not made comparisons of species diversity between years for this reason. However, the data are consistent within years and do permit inter-site comparisons. Data from spring of 2005 are used to illustrate specific points when appropriate. Estimates of *A. petiolata* abundance and total non-*A. petiolata* vegetation cover are reliable for evaluation of changes over time over time.

SITE OVERVIEWS

The eight study sites varied from Southern Floodplain Forest to Dry-Mesic and Dry Southern Forests (MNFI 2003) (Table 6). Site species richness ranged from 17 to 59 total species occurring in the sampling quadrats (Table 7) including *A. petiolata*, which is present at all sites. Of these, native species accounted for 81.6 to 96.9% of the total species observed with perennial forbs representing the single most common growth form. Species inventories for each site are provided (Appendix 1) as are species lists with abundance data from each sampling period (Appendix 2). I found earthworms at all sites where I have looked for them (Box Woodlot, Fernwood, Ives Rd., Lux Arbor, Russ Forest, Shiawassee) and expect that they are also present at the remaining sites. Complete descriptions of the eight sites are presented in Chapter 2 while selected features and diversity information are discussed below. Site abbreviations given here are used in the figures.

SITE CHARACTERIZATIONS

Box Woodlot (BW): Box Woodlot is a remnant Southern Mesic Forest (MNFI 2003) surrounded by agricultural fields. It has the lowest overall diversity of all sites by multiple measures. In spring of 2005 *A. petiolata* occurred in 19 of 20 quadrats had the highest relative importance value (*RIV*).

Fernwood Botanic Garden (FW): Fernwood is a Dry-Mesic Southern Forest (MNFI 2003) with high species richness and is the only site where *A. petiolata* occurred in 20 of 20 quadrats during all years.

Fort Custer Military Training Facility (FC): Fort Custer is a Dry-Mesic Southern Forest (MNFI 2003) whose occasional open-grown oaks indicate that it is likely a degraded oak savanna. It has the second highest species richness of all the sites. In spring of 2005 *A. petiolata* occurred in 11 of 20 quadrats and had the highest *RIV*.

Ives Road Fen Preserve (IR): The site at Ives Road is a Dry-Mesic Southern Forest (MNFI 2003) situated between a restored upland prairie and a Southern Floodplain

Forest and has an intermediate level of plant diversity. In spring of 2005 *A. petiolata* occurred in 19 of 20 quadrats and had the second highest *RIV* (9.5) after the native perennial forb *Sanicula gregaria* (*RIV* = 14).

Lux Arbor (LA): Lux Arbor is a Dry-Mesic/Dry Southern Forest (MNFI 2003) that has a low level of plant diversity relative to most other sites and has the lowest percentage of native species. Logging activity at the study site in spring 2005 caused substantial disturbance to the under- and overstory communities. In spring of 2005 *A. petiolata* occurred in 15 of 20 quadrats and had the highest *RIV* of all species.

Pinckney State Recreation Area (PR): The Pinckney site is a high quality Dry-Mesic Southern Forest (MNFI 2003) with intermediate diversity but a high proportion of native species. In spring of 2005 *A. petiolata* occurred in 20 of 20 quadrats and had the highest *RIV* of all species.

Russ Forest (RF): The Russ Forest site is an old growth Dry Southern Forest (MNFI 2003) with lower species richness but a high proportion of native species. In spring of 2005 *A. petiolata* occurred in 20 of 20 quadrats and had the second highest *RIV* (11.1) after the native tree *Acer saccharum* (*RIV* = 33.7).

Shiawassee YMCA Camp (SH): The Shiawassee site is a Southern Floodplain Forest (MNFI 2003). The sampling transects extend from the drier second bottom of the Shiawassee River valley onto the first bottom floodplain (Tepley et al. 2004). Shiawassee had the highest total number of species of all sites but was dominated by adventives. Quadrats on the first bottom were subjected to extensive flooding following heavy rains in spring of 2004 which resulted in significant changes in species composition and abundance. The relative abundance of another invasive plant, *Lysimachia nummularia*, more than doubled by spring of 2005 following disturbance from the 2004 floods (*RIV* = 25.6) and displaced *A. petiolata* as the most important plant (*RIV* = 16.6). In spring of 2005 *A. petiolata* occurred in 18 of 20 quadrats but was less abundant than it had been in previous years.

SITE-LEVEL DIVERSITY AND IMPACTS

Effects of Deer

The density of deer populations at the county level (Table 6) was negatively but insignificantly correlated with site native species richness (Figure 10, Spearman rank correlation $r_s = -0.6347$, $P = 0.0909$). Although deer browse may serve to reduce native plant diversity or richness and selectively facilitate *A. petiolata* invasions as others have found (Kalisz et al. 2003), deer cannot be held directly responsible for the patterns of plant communities observed in these data. First, because these data are observational, I cannot interpret causality from them. Second, deer are known to respond positively to habitat fragmentation (Horsley et al. 2003) while plant diversity is know to respond negatively (Higgins et al. 2003). This suggests that although deer can directly reduce plant species richness, the relationship between deer density and plant diversity could be derived from larger scale patterns of land use and habitat fragmentation. A separate factorial study of the impacts of deer browse and *A. petiolata* invasions on native plant communities in southern Michigan is ongoing and will address these concerns directly in the future (Evans unpublished).

Native vs. Exotic Species Richness

Native and exotic species richness (SR) are positively correlated at the site level (Figure 11) (Spearman rank correlation = 0.9728, $P < 0.05$) in keeping with observations from many other systems. As Stohlgren et al. (e.g. 1999a, 2003) have pointed out, this trend is indicative of the relative suitability of the sites to plant growth in general and shows that invasive species respond to the same site factors as natives. Other site factors described below are broadly correlated with diversity. Lux Arbor was excluded from this analysis because a disproportionately large number of exotic species appeared there in 2005 following disturbance from logging activities that other sites did not experience.

Distance from public roads appears to separate species rich sites from species poor ones and those with high diversity ($-\ln D_{GM}$) from those with low diversity. Box Woodlot, Lux Arbor, and Russ Forest, which have the fewest native species and low $-\ln D_{GM}$, are each bordered along one or more sides by public or frequently used roads from which the sampling transects are visible. In contrast, Shiawassee and Ft. Custer are the most species rich sites and are much less accessible. The remaining sites with intermediate richness are accessible to the public by foot except for Ives Rd., which is closed to the public. Shiawassee, which has the highest total species richness, also has low diversity ($-\ln D_{GM}$) and high dominance (d_{GM}). While the other sites that share these properties are easily accessible to human as described above, Shiawassee is less accessible but is subjected to natural disturbances from periodic flooding which has led to dominance by two disturbance adapted invasive plants (*A. petiolata* and *L. nummularia*). The mean conservativeness ($\overline{C}$) and *FQI* of native species (Table 2) are not as clearly separated by proximity to roads or disturbance, although *FQI* is more often lower in the species poor sites. This shows that although proximity to roads is correlated with species richness, it is not necessarily indicative of which species are present.

The Fernwood site stands apart from the others in its extent of *A. petiolata* invasion within the sampling area. *Alliaria petiolata* dominated the local community with a relative cover of 57.4% in spring of 2005 (Appendix 2). Fernwood had the lowest diversity and highest dominance of all sites as measured by $-\ln D_{GM}$ and d_{GM} (calculated with *A. petiolata*) (Table 7). However, when *A. petiolata* was excluded from these metrics this site had the highest diversity and evenness within the residual community by both measures. The difference between $-\ln D$ and $-\ln D_{GM}$ at Fernwood in spring of 2005 was 2.9015, which is greater than at any other site. This means that the probability of two individual selected randomly from the community belonging to the same species is over 18 times greater ($e^{2.9015}$) when *A. petiolata* is included than for the residual community without *A. petiolata*. The other species present, though numerous, neither become abundant relative to *A. petiolata* nor differ in their abundances relative to each other. The invasion at the Fernwood study area appears to be more advanced than at other sites as indicated by the spatial and vegetative dominance of *A. petiolata*. The dampening of variance in native species abundance was not observed to this extent elsewhere, and I believe that this may be an impact of *A. petiolata* invasion. Because Allee effects can prevent some species from persisting as very small populations (Allee 1931 *in* Begon et al. 1996) I expect that some native species may be lost at this site if *A. petiolata* remains abundant.

DIFFERENCES BETWEEN SITES

The relative distribution of species abundance was similar across sites at the quadrat scale but less so at the site scale (Table 8). Dunn-Sidak adjusted Kolmogorov-Smirnov two-sample tests for cumulative abundance of the mean rank-abundance data show few significant differences between the distributions at the quadrat scale (Table 8, top). No tests were significant within the 2003 data. The only significant differences in 2004 – 2005 were between sites with the highest high diversity (i.e. Ft. Custer) and those with the lowest diversity (i.e. Box Woodlot and Lux Arbor). This implies that, at the quadrat scale, the relative distributions of species that *A. petiolata* interacts with are similar across sites.

Tests for differences in the distribution of the summed data were significant between the three least species rich sites (Box Woodlot, Russ Forest, and Lux Arbor) and many of the more species rich sites at the transect scale (Table 8, bottom). Box Woodlot in particular, which had the lowest species richness, *FQI*, and $\overline{C}$ (Table 7), stands out as different from the greatest number of sites across all sampling dates. Fort Custer, which had the highest *FQI* and the most evenly distributed species, was significantly different from sites with lower species richness and sites such as Shiawassee that had highly skewed species distributions. While at the quadrat scale there were few differences in the relative distributions of species, sites differed greatly at the site-scale in ways that correspond with observations.

ALLIARIA PETIOLATA INVASION PROCESSES

Effect of Site on *A. petiolata* Presence and Native Species Richness

Native species richness in the quadrats varied by site and *A. petiolata* presence or absence, and the interaction between site and *A. petiolata* presence was significant (Figure 12, Table 9). The main effect of site was significant during all three years, and the main effect of *A. petiolata* presence on native species richness was significant in 2004 and marginally significant in 2005. The most interesting finding from these tests, though, was the significance of the interaction between site and *A. petiolata* presence in 2004 and 2005. In the sites with higher species richness native species richness was higher in quadrats where *A. petiolata* was absent, while at sites with the lowest species richness, native species richness was highest in quadrats where *A. petiolata* was present. This unexpected finding indicates that different processes are affecting *A. petiolata* at these different sites. Specifically, it suggests that competition with residents may be reducing the probability of *A. petiolata* establishment at the species rich sites, while at the species poor sites resource limitation or environmental stress may be more important in restricting *A. petiolata* establishment probability than competition.

Quadrat Level Correlations

The relationship of quadrat scale native species richness to relative *A. petiolata* abundance (Figure 13) was variable and showed similar patterns to the categorical analysis of *A. petiolata* presence or absence. The number of significant relationships (from Spearman rank correlations at $\alpha = 0.05$) increased from two in the spring of 2003 (Ft. Custer, Ives Rd.) to five in the spring of 2004 (Fernwood, Ft. Custer, Ives Rd., Pinckney, Shiawassee) and six in spring of 2005 (Fernwood, Ft. Custer., Ives Rd., Lux Arbor, Pinckney, Shiawassee). The negative coefficients of these correlations suggest that biotic resistance may play a role in directing *A. petiolata* invasions at some sites.

Contrary to the expectation set by Lundholm and Larson (2004), the results from this and the next analysis lead to similar overall conclusions using absolute or relative abundance data, although the correlations that used relative abundance data were a better fit in several cases and were statistically significant more often. I have only presented the relative abundance analyses in full for this reason.

Linking Invasion Patterns Across Scales

The varied patterns of *A. petiolata* invasion within sites are explained in part by the native species richnesses of the sites. I evaluated the relationship of the Spearman rank correlation coefficients from the quadrat scale correlations (Figure 13) from previous section) with site-level native species richness using Spearman rank correlations. These were significant during both 2004 and 2005 (Figure 14, $P = 0.1361$, 0.0165, and 0.0396 for 2003 – 2005 respectively). The analyses that used absolute *A. petiolata* abundance (not shown) were similar, although the relationships were were only significant during spring 2004 and were marginally significant in 2003 and 2005 ($P =$ 0.0687, 0.0138, and 0.0621 for 2003 – 2005 respectively). The correlations between sites species richness and the correlation coefficients were negative in all cases for both absolute and relative *A. petiolata* abundance.

These analyses suggest two general patterns. First, while both absolute and relative abundances measures of *A. petiolata* are correlated with native species richness in similar ways, the relative abundance model provides a better fit to the data. Because the absolute abundance measure is unbounded by species richness, quadrats with any number of species can have high absolute *A. petiolata* cover, but relative abundance must decrease as a function of species richness. Thus, the variance in species richness should be less when expressed as a function of relative *A. petiolata* abundance than of absolute *A. petiolata* abundance and make for a better predictive model.

Second and more importantly, this shows that the relationship between quadrat native species richness and *A. petiolata* abundance becomes more significant and negative as the sites' native species pools increase. There are two possible explanations for this. Either *A. petiolata* causes species richness to decrease as it becomes more abundant within quadrats at the more species rich sites or those quadrats with greater species richness are resistant to *A. petiolata* invasion or dominance. This latter explanation is in keeping with observations of biotic resistance in other systems at the quadrat scale (Levine et al. 2004). That the relationship is only significant at sites with higher species richness suggests that there may be a threshold of species richness below which biotic resistance is not effective or detectable. When coupled with the factorial analysis of *A. petiolata* presence versus absence across the eight sites, the evidence favors concluding that *A. petiolata* is responding to variation in species richness much more than it is causing it because of differences in species richness between invaded and uninvaded quadrats. Because the data do not allow analysis of change over time I cannot interpret the causality of this relationship. However, observation of new invasions in previously uninvaded quadrats may highlight correlations between species richness and invasion probability.

Predicting Invasion Probability

Logistic Regression Analysis

Within the 57 initially uninvaded quadrats 33 became invaded by spring of 2004, while 24 did not (Table 10). I used logistic regressions to test the hypothesis that native and total species richness would be predictive of invasion probability within the quadrats that were initially uninvaded and found that the probability of a quadrat becoming invaded increased as its species richness decreased. The quasi-complete separation of data from Pinckney prohibited asymptotic maximum likelihood estimation of logistic regression parameters. However, exact logistic regression can estimate parameters using alternative methods for data with complete or quasi-complete separation and can be executed with the "exact" statement in PROC LOGISTIC (Derr 2000, SAS Institute 2001). Exact logistic regression with terms for invasion outcome in 2004 ('Invade 2004') as the dependent variable and site as the independent variable was significant (Score test statistic = 12.5051, Exact P = 0.0375) when all seven sites are included (Fernwood was excluded from all invasion analyses because 20 of 20 quadrats were initially invaded). However, the Pinckney site alone appeared to drive this relationship, as its removal rendered insignificant both the exact regression and the conventional maximum likelihood estimated logistic regression, which could then be run without separation problems, of Invade 2004 on site, (Exact regression: Score test statistic 3.7315, Exact P = 0.6370; Maximum likelihood estimated logistic regression: Wald's χ^2 = 3.5914, df = 5, P = 0.6096). Site effects were not included in subsequent models based on these findings, although data from the Pinckney site were retained to avoid bias from data selection.

To test for the relationship between initial native or total species richness and *A. petiolata* invasion probability, I fit single-predictor logistic models to the data from the 57 initially uninvaded plots and found that:

(1) Predicted logit of (Invade 2004) = 1.5780 + (–0.2556)*Native SR 2003

and:

(2) Predicted logit of (Invade 2004) = 1.5299 + (–0.2362)*Total SR 2003

Differences in model fit estimates and predictions were negligible, so only the fit parameters for native species richness are given (Table 11) as they were marginally more significant. These models indicate that the log of the odds of a sampling quadrat being invaded in 2004 was negatively related to the native ($P = 0.0296$) (Figure 15) and total ($P = 0.0339$) species richness in that quadrat in 2003. Put otherwise, the higher a quadrat's species richness was in 2003, the lower its probability of being invaded the following year was. For an increase in native richness of one species, the probability of invasion correspondingly decreased from 1.0 to 0.7746 ($e^{-0.2556}$ Table 11). Similarly, for an increase in native richness of five species, the odds of invasion decrease from 1.0 to 0.2786 ($e^{5*[-0.2556]}$ Table 11). Repeating the test in the same quadrats with species data from 2005, when our plant identification ability had improved showed that:

Predicted logit of (Invade 2004) = 1.5990 + (–0.1908)*Species Richness 2005

This result was more highly significant ($P = 0.0117$), and the sign of the estimated effect parameter is concurrent with the test of the 2003 data. The consistency of these finding over several years as these invasions have progressed suggests that the differences between these sets of quadrats did not necessarily result from *A. petiolata* invasion but, rather, that they directed it.

PATTERNS OF INVASION AND POSSIBLE MECHANISMS

The changing relationship between *A. petiolata* presence (Figure 12) or abundance (Figure 13) and native species richness across the eight sites suggests that properties of either the sites themselves or the resident communities influence the relative success of *A. petiolata*'s invasions. While species richness was negatively correlated with *A. petiolata* abundance in the most species rich sites (Figures 13 & 14) and invasion probability in 2004, at sites with low diversity there was a positive association between species richness and *A. petiolata* presence and zero relationship with *A. petiolata* relative abundance. This suggests a potential dichotomy between the "rich get richer" hypothesis (Stohlgren et al. 2003), which predicts that areas with greater numbers of species and higher resource availability are thus more likely to be invaded or colonized by additional species, and biotic resistance, which predicts that those same areas should not be invasion prone. The finding that exotic and native species richness are positively correlated at the site scale (Figure 11) suggests that extrinsic factors like resource availability or habitat stability make some sites generally better suited to plant growth than others. If resource availability limits establishment probability, one would expect *A. petiolata* establishment to be greatest within sites where the availability of resources was greatest. But simultaneously, species richness within sites is likely positively correlated with resource availability. At the sites with higher species richness, the increased survival probability expected in resource rich areas is thus offset by increased competition from the resident community, which is richer at those same locations. Others have shown that as species richness increases, the availability of resources becomes locally reduced as the resident species consume them (Naeem et al. 2000), and crowding by dense stands of residents reduces suitable germination sites for arriving seeds (Kennedy et al. 2002) as per Tilman's R^* (Tilman 1976) and stochastic niche (Tilman 2004) theories. True to these findings, *A. petiolata* more frequently establishes within species rich sites in areas of lower species richness. Conversely, at species poor site (i.e. Box Woodlot), the opposite occurs, and *A. petiolata* establishes first in the areas with the greatest species richness (Figure 12). The lower diversity of both native and exotic species (Figure 11) at these sites suggests that resources or physiological stress likely limit plant growth, and that survival probability within these sites is lowest where species richness is lowest.

Alliaria petiolata's variable patterns of establishment did not prevent it from spreading into new areas over time (Chapter 2). Within the species-rich sites, *A. petiolata* first established in the species poor areas where competition was least limiting. Given enough time, propagule pressure from the established invader populations should eventually overwhelm the residents and allow *A. petiolata* to spread into areas where establishment and survival probabilities were potentially limited by increased competition with resident species. If *A. petiolata* is able to weaken competitors by disrupting their mycorrhizal associations (Roberts and Anderson 2001, Stinson and Klironomos 2005) and through direct allelopathy, it is possible that in time it could come to dominate even the most "resistant" areas. At the species-poor sites, *A. petiolata* initially became established where resource availability and competition were likely greatest, but because the diversity in these sites was so low, competition was not significant enough to limit or prevent establishment. Once established, populations of *A. petiolata* could similarly produce a steady seed rain into the remaining lower diversity areas within the sites where resource limitation likely reduced the probability of establishment. Over time, mass effects of this continuous seed production would likely result in some *A. petiolata* plants becoming established even in these less favorable areas and ultimately spreading as I have observed (Chapter 2).

Biotic resistance (generally) appears to be especially important in limiting or slowing *A. petiolata* invasions in sites with higher species richness, but resource limitation seems to resist establishment of native and exotic species alike in sites with lower species richness. Tilman's (2004) stochastic niche theory predicts the biotic resistance observed in the species rich sites, and Stohlgren et al's (2003) "rich get richer" hypothesis predicts what I observed at the lowest diversity sites, but I believe that the progressive inversion of the relationship between local native richness and invader presence or abundance across a larger-scale natural diversity gradient is novel and suggests a possible union between the two hypotheses.

SUMMARY AND CONCLUSIONS

Populations of *A. petiolata* that invade natural areas in Michigan exhibit complex interactions with resident species assemblages that vary both spatially and temporally. At larger scales the relationship of native and exotic species richness is positive (Figure 11) as others have previously shown. But in some communities I found a negative correlation between *A. petiolata* abundance and native species richness which suggests that either *A. petiolata* invasions lead to reductions in diversity at the quadrat scale (0.5 m^2), that biotic resistance locally impedes the invasion process, or that a combination of the two scenarios is played out over time.

POTENTIAL IMPACTS

The patterns of native species richness and *A. petiolata* abundance at the Fernwood site where *A. petiolata* dominates the community indicate that *A. petiolata* is likely negatively affecting native plant populations there. Allelopathic, competitive, and antimycorrhizal effects are expected to be greatest where *A. petiolata* is widespread and has high absolute abundance (Roberts and Anderson 2001). If *A. petiolata* invasions do have negative impacts such as local extinctions, Fernwood may be the best place to begin looking for them among my study sites in future years.

ALLIARIA PETIOLATA AND THEORIES OF INVASION PROCESSES

The size of sites' species pools dictates the relationship between *A. petiolata* presence or abundance and native species richness within quadrats. As the site-level species pool increased, the relationship between quadrat-scale species richness and *A. petiolata* abundance became increasingly negative. As this happened, species richness shifted from being greatest where *A. petiolata* was present to being greatest where it was absent. One possible explanation of this correlation which would be in keeping with Tilman's stochastic niche theory (Tilman 2004) is that biotic resistance, mediated by resource competition, is only biologically significant or detectable above a minimum threshold of species richness. Higher species richness at the site level should indicate a greater breadth of resources present but should be simultaneously correlated with a greater partitioning of those resources between species. The odds of establishment thus diminish as local species richness increases and the available portion of the resource pool is reduced. The alternate hypothesis is that native species richness was more uniformly distributed prior to *A. petiolata* invasion and that *A. petiolata* has significantly reduced diversity where it has become abundant. However, my observation that the probability of *A. petiolata* invading is greatest where local species richness is lowest indicates that biotic resistance is primarily responsible for this pattern. My data collection did not predate the initial invasions of these sites, so I cannot say which, if either, is correct. If *A. petiolata* does in fact reduce diversity or richness, I should see the negative relationship between quadrat-scale species richness and *A. petiolata* abundance degrade within the more species rich sites as *A. petiolata* continues to spread.

A hardy species that can survive where resources are limiting to most others and that has a plastic response to variation in resource availability should be able to (1) colonize less favorable areas that other species cannot, (2) potentially perform better where those resources are more abundant, and (3) increase when rare. *Alliaria petiolata* appears to fit this profile as it has invaded even the least and most diverse sites and has spread throughout them over time. If species richness is indicative of resource abundance this indicates that *A. petiolata* is making tradeoffs between its competitive ability and overcoming obstacles to establishment. Over time, natural selection should variably favor hardier individuals with greater tolerance of resource stress (survivors) at species poor sites and individuals with greater competitive abilities (competitors) at species rich sites. This hypothesis could be tested empirically in the future by growing *A. petiolata* from high and low diversity sites in a common garden experiment or by exchanging seeds between species rich and species poor sites and evaluating their survival and fitness across a range of conditions. Additional measurements of resources such as light, water, space availability and soil properties at the eight current study sites could provide further tests.

Taken as a whole, this suggests that biotic resistance and enhancement (the rich get richer) are not diametrically opposing concepts, but, rather, are endpoints along a continuum of tradeoffs between resource competition and stress tolerance against a background of stochastic establishment and survival probabilities. Continued monitoring at these eight sites may further elucidate the complex relationships between diversity, competition, and invasibility and enrich current models which have only found such tradeoffs in plant invasions across gradients of scale.

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Table 6. Michigan sites selected for long-term monitoring of *A. petiolata* invasion, county, GPS coordinates, identities and diameter at breast height (DBH) measurements of principal canopy trees, and Michigan Natural Features Inventory (2003) community types. Deer density estimates are county wide and may not reflect local population sizes within the study sites (MDNR 2006).

Site Name	County	Latitude	Longitude	Dominant Canopy Trees (DBH cm)	MNFI Community Type	Deer/km^2
Box Woodlot	Ingham	42.689479°	-84.489951°	sugar maple (67, 74), silver maple (82, 80), bur oak (69, 67), sycamore (74), green ash (46, 35)	Southern Mesic Forest	17.0
Fernwood	Berrien	41.867417°	-86.346351°	White oak (44), red oak (80), tulip tree (51, 60), black walnut (33, 56, 64), hackberry (12), American elm (54), redbud (25), black oak, black cherry	Dry-Mesic Southern Forest	7.1
Ft. Custer	Kalamazoo	42.305018°	-85.325651°	Black oak (81), white oak (77, 78), shagbark hickory (76), sugar maple (76), black walnut (43, 46)	Dry-Mesic Southern Forest	13.6
Ives Road	Lenawee	41.980206°	-83.932771°	White oak (91), red oak, shagbark hickory	Dry-Mesic Southern Forest	10.5
Lux Arbor	Barry	42.492880°	-85.466543°	Red oak (66, 89), white oak (46, 63), black cherry (46)	Dry-Mesic/Dry Southern Forest	25.3
Pinckney	Livingston	42.440907°	-84.005645°	White oak (105), black walnut (17), black cherry (51), sugar maple (18), red oak (40)	Dry-Mesic Southern Forest	17.4
Russ Forest	Cass	42.011616°	-85.970255°	Black oak (83), white oak (79, 83), black cherry (30, 49), tulip tree (84)	Dry Southern Forest	14.9
Shiawassee	Shiawassee	42.885813°	-84.046135°	Silver maple (28), cottonwood (256, 81), black walnut (92), red ash (54), black cherry (43), basswood (39), hackberry (29)	Southern Floodplain Forest	13.8

Table 7. Results of Floristic Quality Assessment of site inventories (all years) and diversity indices for spring of 2005 data.

Site	SR_N	SR	$\overline{C}_N$	$\overline{C}$	FQI_N	FQI	$-\ln D$	$-\ln D_{GM}$	d	d_{GM}
Box Woodlot	16	17	3.3	3.1	13.0	12.6	2.4499	1.1299	0.4302	0.4871
Fernwood	41	43	3.9	3.9	24.7	24.1	3.9545	1.0530	0.2788	0.5744
Ft. Custer	52	58	4.0	3.6	28.7	27.2	3.1071	2.6566	0.1169	0.1599
Ives Rd.	44	48	3.9	3.6	25.8	24.7	2.5314	2.4527	0.2053	0.2234
Lux Arbor	34	38	3.1	2.5	17.2	15.6	2.3787	1.9157	0.2343	0.2443
Pinckney	38	39	3.9	3.6	21.9	21.3	2.6944	2.3856	0.1569	0.1763
Russ Forest	31	32	3.9	3.8	21.7	21.4	1.3456	1.3166	0.4805	0.5312
Shiawassee	52	59	3.5	3.1	25.3	24	1.5999	1.3924	0.4357	0.5557

SR = Species richness; C = mean coefficient of conservatism. *FQI* = Floristic Quality Index. These three indices were calculated from overall site inventories (all years) for all species (no subscript) and for native species only (subscripted with "N"). $-\ln D$ = negative natural logarithm of Simpson's Diversity Index; d = Berger Parker index of dominance (Magurran 2004). These two indices were calculated from spring 2005 data for all species except *A. petiolata* (no subscript) and for all species including *A. petiolata* (subscripted with "GM").

Table 8. Results of Kolmogorov-Smirnov two sample tests for differences in mean (above) and summed (below) relative abundance distributions of species data. Years 03, 04, and 05 show results from 2003, 2004, and 2005 respectively. Results above the diagonal are from fall data, and those below the diagonal are from spring data. Significant Dunn-Sidak adjusted *P*-values are shown as: $P \leq 0.0018$ = ***d**. Unadjusted *P*-values are shown as: $P \leq 0.05$ = *****, $P \leq 0.01$ = ******.

Site	Box Woodlot			Fernwood			Ft. Custer			Ives Rd.			Lux Arbor			Pinckney			Russ Forest			Shiawassee		
Year: 20-	03	04	05	03	04	05	03	04	05	03	04	05	03	04	05	03	04	05	03	04	05	03	04	05
Mean Data																								
Box Woodlot								*	*d															
Fernwood																								
Ft. Custer		*d	*d																	*d				
Ives Rd			*d																					
Lux Arbor								*d	*d			*d												
Pinckney			*																					
Russ Forest																								
Shiawassee																								
Summed Data																								
Box Woodlot				**	*	**		*d	*d		*d	*d			*d	*	**	*d				*d	*d	*d
Fernwood	*d	*d	*d						*d															
Ft. Custer	*d	*d	*d												**			*d			*d	**		*d
Ives Rd	**	*d	*d																		**	*		
Lux Arbor			*	*	*d	*		*d	*d		**	**										**		
Pinckney		*d	*d				*																	
Russ Forest			*		*d	*		*d	*d		*	**												
Shiawassee	*d	*d	*d						*				**			*			*					

Table 9. Two-way factorial GLM of quadrat native species richness by *A. petiolata* presence or absence and Site as main effects.

Source	Sum-of-Squares	*df*	Mean-Square	*F*-ratio	*P*
2003[a]					
A. petiolata Presence	4.9124	1	4.9124	1.9365	0.1665
Site	316.1744	6	52.6957	20.7726	0.0000
A. petiolata x Site	24.9381	6	4.1563	1.6384	0.1419
Error	319.6357	126	2.5368		
2004[a]					
A. petiolata Presence	19.3326	1	19.3326	7.5952	0.0067
Site	757.2076	6	126.2013	49.5804	0.0000
A. petiolata x Site	46.0254	6	7.6709	3.0136	0.0087
Error	320.7187	126	2.5454		
2005[a, b]					
A. petiolata Presence	12.5649	1	12.5649	3.1243	0.0800
Site	744.3778	5	148.8756	37.0185	0.0000
A. petiolata x Site	59.1424	5	11.8285	2.9412	0.0158
Error	434.3386	108	4.0217		

a Fernwood was excluded from analysis because all 20 quadrats were invaded.

b Pinckney was excluded from analysis because all 20 quadrats were invaded.

Table 10. Frequency of invasion events in 2004 in plots that were uninvaded in 2003.

Site	Uninvaded	Invaded	Total
Box Woodlot	1	3	4
Ft. Custer	9	4	13
Ives Rd.	1	1	2
Lux Arbor	4	7	11
Pinckney	0	10	10
Russ Forest	6	5	11
Shiawassee	3	3	6
Total	24	33	57

Table 11. Logistic regression analysis of invasion probability by native species richness in 57 sampling quadrats that were not invaded by *A. petiolata* in spring 2003.

Predictor	β	SE β	Wald's χ^2	*df*	*P*	e^{β} (odds ratio)
Constant	1.5780	0.6518	5.8601	1	0.0155	NA
Native Species Richness	-0.2556	0.1175	4.7296	1	0.0296	0.774
Test			χ^2	*df*	*P*	
Overall Model Evaluation						
Likelihood ratio test			5.2418	1	0.0220	
Score test			5.0948	1	0.0240	
Wald test			4.7296	1	0.0296	
Goodness-of-fit test						
Hosmer & Lemeshow			8.8263	6	0.1836	

Note SAS code: [PROC LOGISTIC; MODEL INVADE_04=NS_03/CTABLE PPROB = (0.1 TO 1.0 BY 0.1) LACKFIT RSQ;]. Cox and Snell R 2 = 0.0879. Nagelkerke R^2 (Max rescaled R 2) = 0.1181. Kendall's Tau-a = 0.2377 Goodman-Kruskal Gamma = 0.3499. Somers's D yx = 0.1768. c-statistic = 66.0%. NA = not applicable.

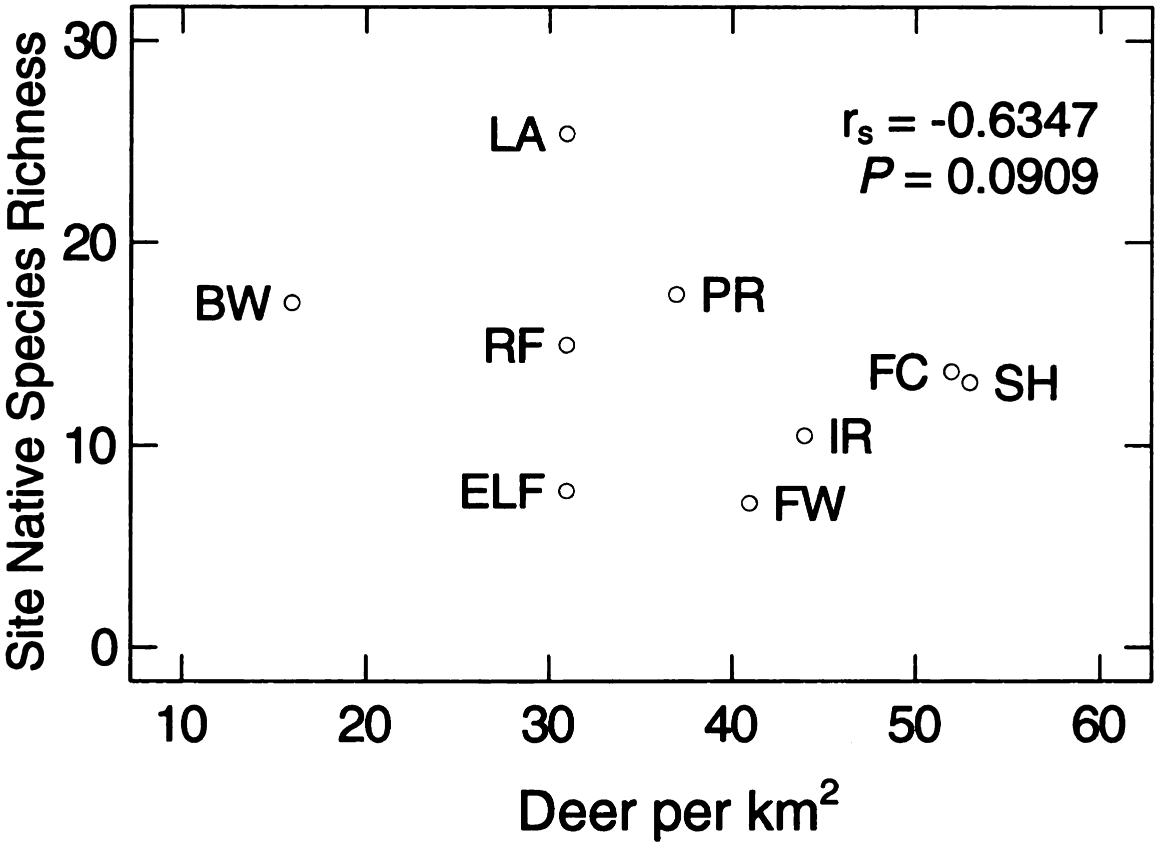

Figure 10. Correlation of site native species richness from 2003-2005 data and county-wide deer-density. Spearman rank correlation coefficient and probability are shown.

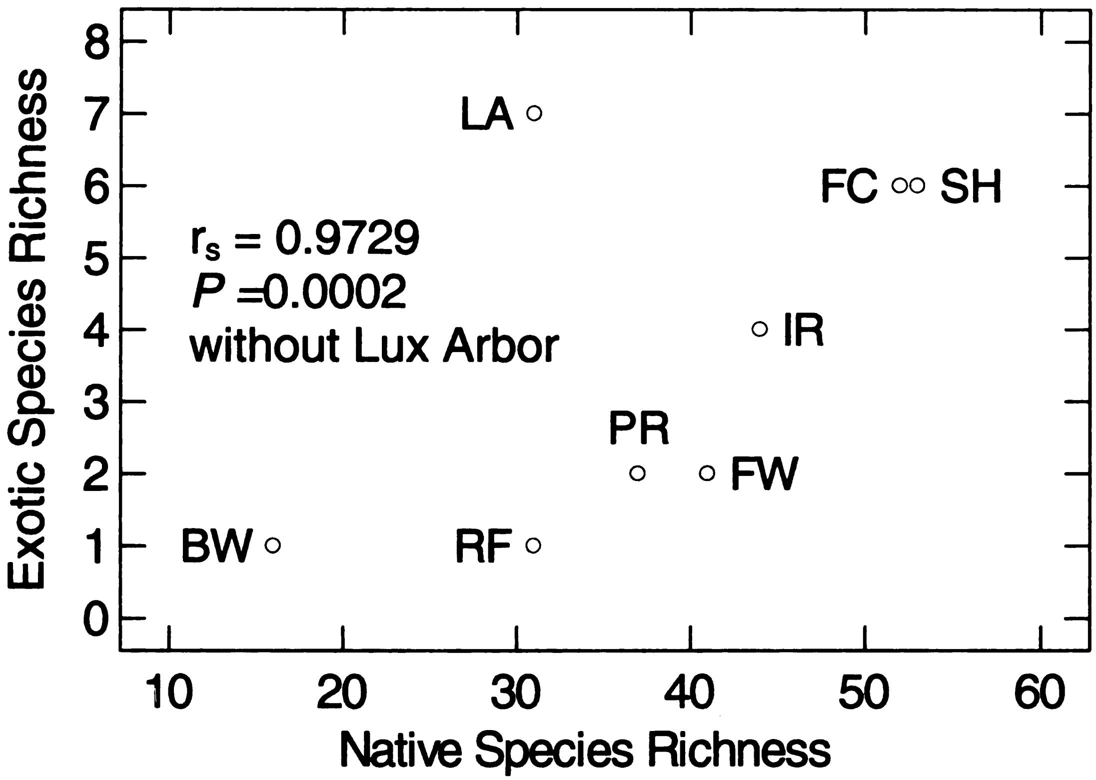

Figure 11. Spearman rank correlation of exotic versus native species richness at the site level. The number of exotic species observed at Lux Arbor (LA) increased disproportionately following extensive soil and canopy disturbance during logging activities in spring 2005. I excluded Lux Arbor from this analysis for this reason.

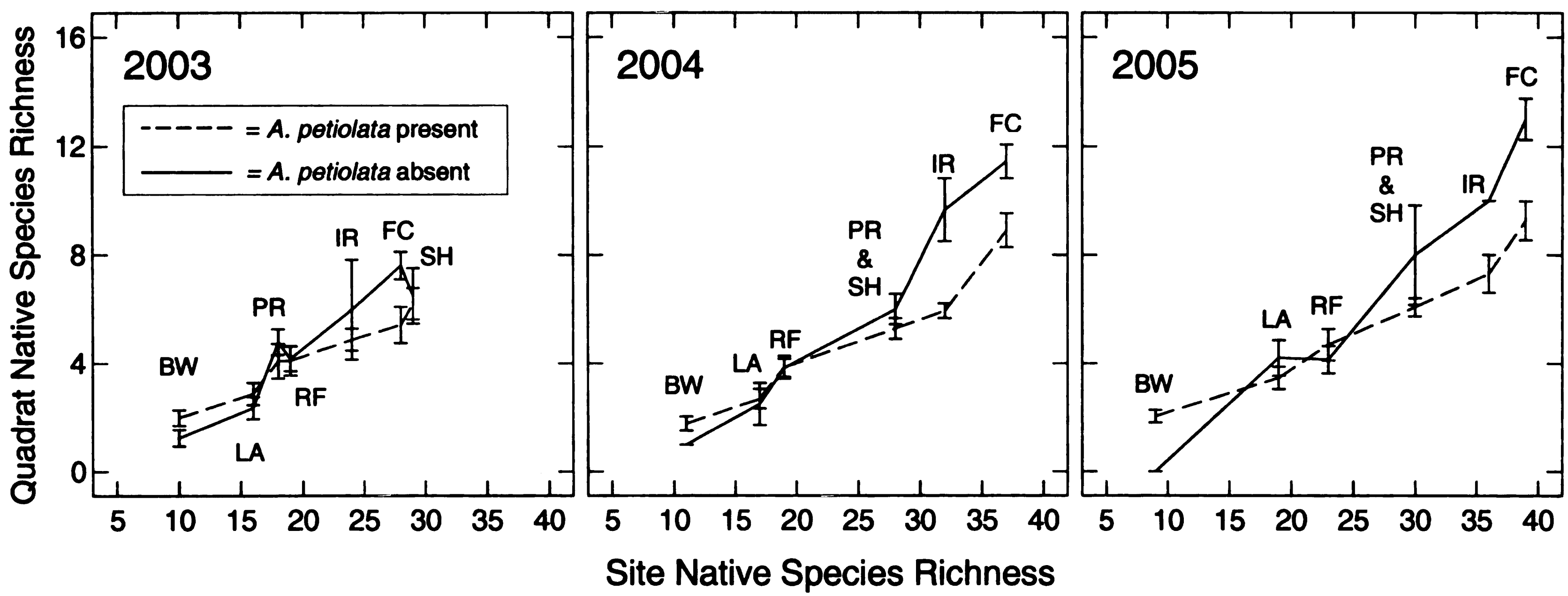

Figure 12. Native species richness (mean ± SE) in quadrats with and without *A. petiolata* versus the total number of native species observed per site on the sampling date. Differences between years in site species richness reflect improved sampling ability, but overall patterns are consistent across years. The reduced variance in uninvaded quadrats over time at some sites was casued by *A. petiolata*'s spread and the decreasing number of ininvaded quadrats.

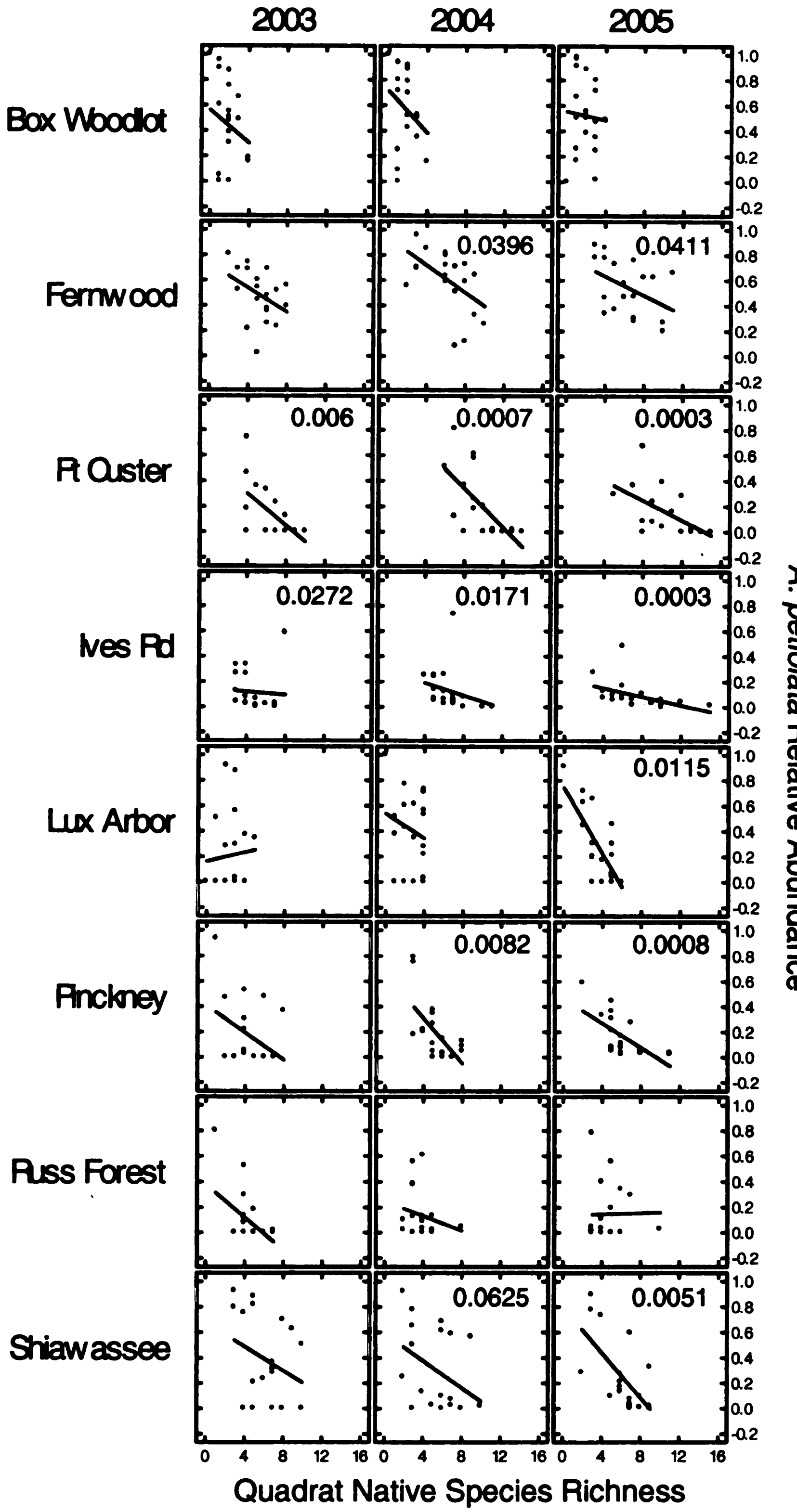

Figure 13. Quadrat native species richness versus *A. petiolata* relative abundance. *P*-values ≤ 0.1 from Spearman rank correlations are shown. Least square regression lines are overlaid to indicate the linear trend from each correlation.

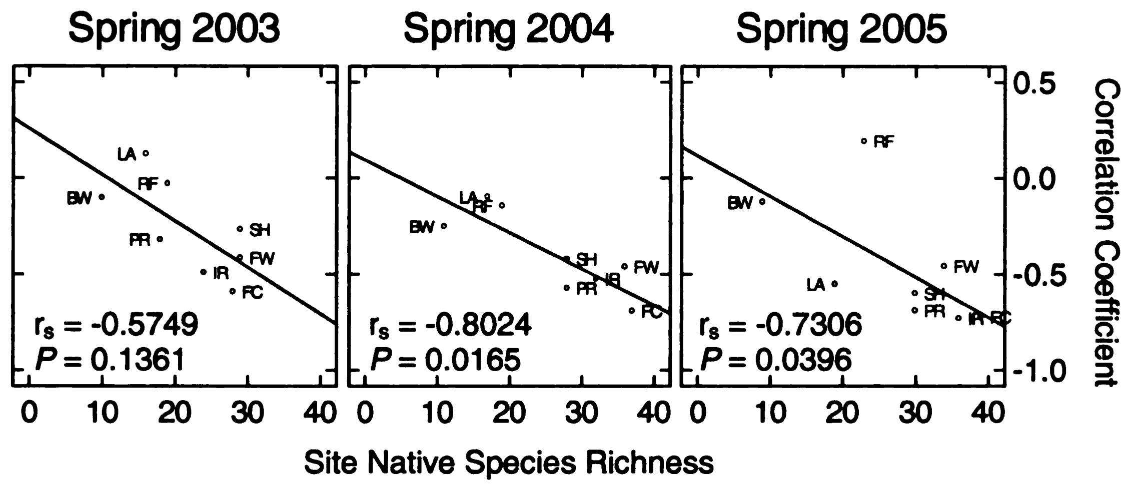

Figure 14. Relationship of correlation coefficients (from figure 13) to site native species richness. Spearman rank correlation coefficients are shown. Least square regression lines are overlaid to indicate the linear trend from each correlation.

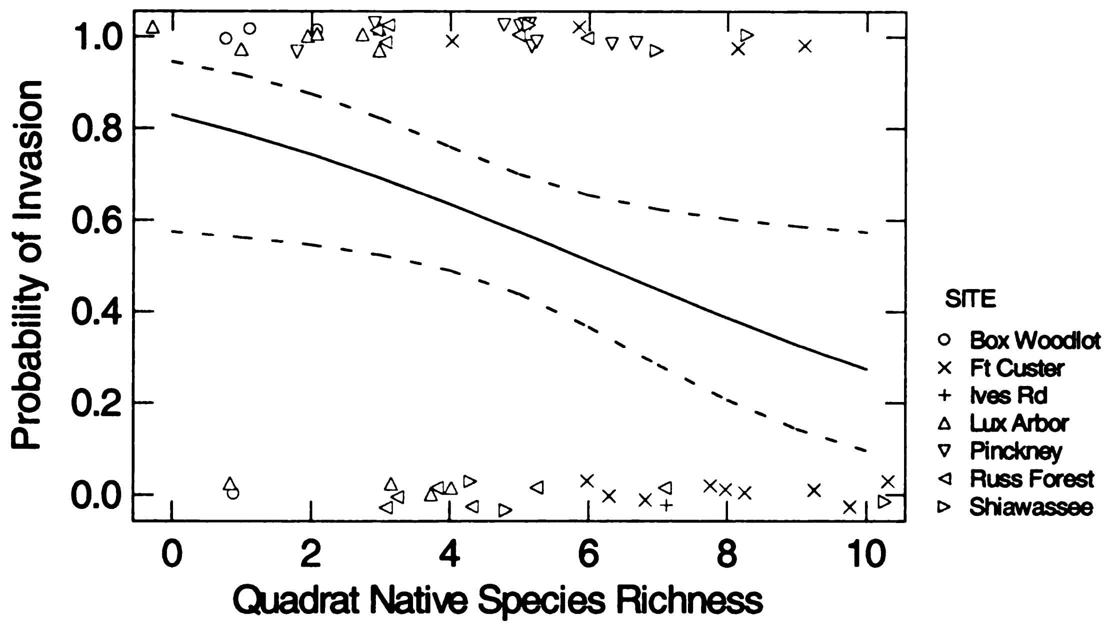

Figure 15. Predicted and observed outcomes of invasion in 2004 of quadrats that were *A. petiolata* free in 2003. Lines represent predicted invasion probabilities and 95% confidence intervals. Quadrats that were invaded in 2004 are show at the top of the frame, while those that were not invaded are at the bottom. Observed data points are jittered to reveal overlapping points.

APPENDIX 1

Appendix 1. Species inventories for all sites from Spring 2003 - Fall 2005. Capitalized scientific names indicate non-native species. Values for C and W indicate coefficients of conservatism and wetness used in floristic quality assessment. Prefixes under physiognomy describe life cycle of species as biennial (B), perennial (P), or annual (A) and growth form as herbaceous (H) or woody (W).

Scientific Name	Common Name	C	W	PHYS
Box Woodlot				
Acer saccharinum	SILVER MAPLE	2	-3	Nt Tree
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb
Erythronium americanum	YELLOW TROUT LILY	5	5	Nt P-Forb
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree
Geum canadense	WHITE AVENS	1	0	Nt P-Forb
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree
Quercus alba	WHITE OAK	5	3	Nt Tree
Quercus macrocarpa	BUR OAK	5	1	Nt Tree
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub
Sambucus racemosa	RED-BERRIED ELDER	3	2	Nt Shrub
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine
Fernwood				
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb
Asimina triloba	PAWPAW	9	0	Nt Tree
Aster cordifolius	HEART-LEAVED ASTER	4	5	Nt P-Forb
Carex blanda	SEDGE	1	0	Nt P-Sedge
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree
Celtis occidentalis	HACKBERRY	5	1	Nt Tree
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb
Dentaria laciniata	CUT-LEAVED TOOTHWORT	5	3	Nt P-Forb
Euonymus obovata	RUNNING STRAWBERRY BUSH	5	5	Nt Shrub
Eupatorium rugosum	WHITE SNAKEROOT	4	3	Nt P-Forb
Fraxinus americana	WHITE ASH	5	3	Nt Tree
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb
Galium asprellum	ROUGH BEDSTRAW	5	-5	Nt P-Forb
Geum canadense	WHITE AVENS	1	0	Nt P-Forb
Glyceria striata	FOWL MANNA GRASS	4	-5	Nt P-Grass
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb
Hydrophyllum appendiculatum	GREAT WATERLEAF	7	5	Nt P-Forb
Hystrix patula	BOTTLEBRUSH GRASS	5	5	Nt P-Grass
Juglans nigra	BLACK WALNUT	5	3	Nt Tree
LAMIUM PURPUREUM	PURPLE DEAD-NETTLE	*	5	Ad A-Forb
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb

Appendix 1. (cont'd)

Scientific Name	Common Name	C	W	PHYS
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb
Polygonatum biflorum	SOLOMON-SEAL	4	3	Nt P-Forb
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree
Quercus alba	WHITE OAK	5	3	Nt Tree
Ranunculus abortivus	SMALL-FLOWERED	0	-2	Nt A-Forb
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb
Sassafras albidum	SASSAFRAS	5	3	Nt Tree
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine
Trillium grandiflorum	COMMON TRILLIUM	5	5	Nt P-Forb
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree
Viola canadensis	CANADA VIOLET	5	5	Nt P-Forb
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb
Viola sororia	COMMON BLUE VIOLET	1	1	Nt P-Forb
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine
Ft. Custer				
Acer rubrum	RED MAPLE	1	0	Nt Tree
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb
Amelanchier laevis	SMOOTH SHADBUSH	4	5	Nt Tree
Amphicarpaea bracteata	HOG-PEANUT	5	0	Nt A-Forb
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb
Aster lanceolatus	EASTERN LINED ASTER	2	-3	Nt P-Forb
BERBERIS THUNBERGII	JAPANESE BARBERRY	*	4	Ad Shrub
Carex cephalophora	SEDGE	3	3	Nt P-Sedge
Celtis occidentalis	HACKBERRY	5	1	Nt Tree
Cinna arundinacea	WOOD REEDGRASS	7	-3	Nt P-Grass
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb
Desmodium glutinosum	CLUSTERED-LEAVED TICK-TREFOIL	5	5	Nt P-Forb
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb
Elymus villosus	SILKY WILD-RYE	5	3	Nt P-Grass
Festuca subverticillata	NODDING FESCUE	5	2	Nt P-Grass
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb
Galium concinnum	SHINING BEDSTRAW	5	3	Nt P-Forb
Galium pilosum	HAIRY BEDSTRAW	6	5	Nt P-Forb
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb

Appendix 1. (cont'd)

Scientific Name	Common Name	C	W	PHYS
Geum canadense	WHITE AVENS	1	0	Nt P-Forb
Impatiens pallida	PALE TOUCH-ME-NOT	6	-3	Nt A-Forb
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub
Onoclea sensibilis	SENSITIVE FERN	2	-3	Nt Fern
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine
Phlox divaricata	WOODLAND PHLOX	5	3	Nt P-Forb
Phryma leptostachya	LOPSEED	4	5	Nt P-Forb
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree
Quercus alba	WHITE OAK	5	3	Nt Tree
Quercus velutina	BLACK OAK	6	5	Nt Tree
RHAMNUS CATHARTICA	COMMON BUCKTHORN	*	3	Ad Tree
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub
RUMEX OBTUSIFOLIUS	BITTER DOCK	*	-3	Ad P-Forb
Sambucus racemosa	RED-BERRIED ELDER	3	2	Nt Shrub
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb
Sassafras albidum	SASSAFRAS	5	3	Nt Tree
Senecio obovatus	ROUND-LEAVED RAGWORT	10	4	Nt P-Forb
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb
Smilax lasioneura	CARRION-FLOWER	5	5	Nt W-Vine
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb
STELLARIA MEDIA	COMMON CHICKWEED	*	3	Ad A-Forb
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree
Urtica dioica	NETTLE	1	-1	Nt P-Forb
Viola canadensis	CANADA VIOLET	5	5	Nt P-Forb
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb
Ives Road				
Acer rubrum	RED MAPLE	1	0	Nt Tree
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree
Agrimonia pubescens	SOFT AGRIMONY	5	5	Nt P-Forb
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb
Allium canadense	WILD GARLIC	4	3	Nt P-Forb
Allium tricoccum	WILD LEEK	5	2	Nt P-Forb
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb
Carex blanda	SEDGE	1	0	Nt P-Sedge
Carex grisea	SEDGE	3	-3	Nt P-Sedge
Carex hirtifolia	SEDGE	5	5	Nt P-Sedge
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree
Celtis occidentalis	HACKBERRY	5	1	Nt Tree
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb
Claytonia virginica	SPRING-BEAUTY	4	3	Nt P-Forb

Appendix 1. (cont'd)

Scientific Name	Common Name	C	W	PHYS
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb
Festuca subverticillata	NODDING FESCUE	5	2	Nt P-Grass
Fraxinus americana	WHITE ASH	5	3	Nt Tree
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree
Geum canadense	WHITE AVENS	1	0	Nt P-Forb
HESPERIS MATRONALIS	DAME'S ROCKET	*	5	Ad P-Forb
Laportea canadensis	WOOD NETTLE	4	-3	Nt P-Forb
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub
LONICERA MAACKII	AMUR HONEYSUCKLE	*	5	Ad Shrub
Morus rubra	RED MULBERRY	9	1	Nt Tree
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree
Prunus virginiana	CHOKE CHERRY	2	1	Nt Shrub
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub
Sambucus canadensis	ELDERBERRY	3	-2	Nt Shrub
Sambucus racemosa	RED-BERRIED ELDER	3	2	Nt Shrub
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine
Symplocarpus foetidus	SKUNK-CABBAGE	6	-5	Nt P-Forb
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine
Trillium grandiflorum	COMMON TRILLIUM	5	5	Nt P-Forb
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb
Viola striata	CREAM VIOLET	5	-3	Nt P-Forb
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine
Lux Arbor				
Acer rubrum	RED MAPLE	1	0	Nt Tree
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree
Actaea pachypoda	DOLL'S-EYES	7	5	Nt P-Forb
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb
Carex cephalophora	SEDGE	3	3	Nt P-Sedge
CHENOPODIUM ALBUM	LAMB'S QUARTERS	*	1	Ad A-Forb
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb
Erechtites hieracifolia	FIREWEED	2	3	Nt A-Forb
ERUCA VESICARIA	ROCKET SALAD; GARDEN SALAD	*	5	Ad A-Forb
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb

Appendix 1. (cont'd)

Scientific Name	Common Name	C	W	PHYS
Geranium robertianum	HERB ROBERT	3	5	Nt A-Forb
Geum canadense	WHITE AVENS	1	0	Nt P-Forb
Juncus tenuis	PATH RUSH	1	0	Nt P-Forb
LEONURUS CARDIACA	MOTHERWORT	*	5	Ad P-Forb
Oxalis stricta	COMMON YELLOW WOOD-SORREL	0	3	Nt P-Forb
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine
Phytolacca americana	POKEWEED	2	1	Nt P-Forb
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree
Quercus velutina	BLACK OAK	6	5	Nt Tree
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub
RUMEX OBTUSIFOLIUS	BITTER DOCK	*	-3	Ad P-Forb
Senecio aureus	GOLDEN RAGWORT	5	-3	Nt P-Forb
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb
TARAXACUM OFFICINALE	COMMON DANDELION	*	3	Ad P-Forb
Thalictrum dasycarpum	PURPLE MEADOW-RUE	3	-2	Nt P-Forb
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine
TRIFOLIUM REPENS	WHITE CLOVER	*	2	Ad P-Forb
Urtica dioica	NETTLE	1	-1	Nt P-Forb
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine
Pinckney				
Acer negundo	BOX ELDER	0	-2	Nt Tree
Acer rubrum	RED MAPLE	1	0	Nt Tree
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb
Amelanchier arborea	JUNEBERRY	4	3	Nt Tree
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb
Carex pensylvanica	SEDGE	4	5	Nt P-Sedge
Carex rosea	CURLY-STYLED WOOD SEDGE	2	5	Nt P-Sedge
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree
Celtis occidentalis	HACKBERRY	5	1	Nt Tree
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub
Desmodium glutinosum	CLUSTERED-LEAVED TICK-TREFOIL	5	5	Nt P-Forb
Dioscorea villosa	WILD YAM	4	1	Nt P-Forb
Fraxinus americana	WHITE ASH	5	3	Nt Tree
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb
Galium concinnum	SHINING BEDSTRAW	5	3	Nt P-Forb
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb
Geum canadense	WHITE AVENS	1	0	Nt P-Forb
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine

Appendix 1. (cont'd)

Scientific Name	Common Name	C	W	PHYS
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb
Potentilla simplex	OLD-FIELD CINQUEFOIL	2	4	Nt P-Forb
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree
Prunus virginiana	CHOKE CHERRY	2	1	Nt Shrub
Quercus alba	WHITE OAK	5	3	Nt Tree
Quercus rubra	RED OAK	5	3	Nt Tree
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub
Rubus flagellaris	NORTHERN DEWBERRY	1	4	Nt Shrub
Sassafras albidum	SASSAFRAS	5	3	Nt Tree
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb
Thalictrum dioicum	EARLY MEADOW-RUE	6	2	Nt P-Forb
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine
Trillium grandiflorum	COMMON TRILLIUM	5	5	Nt P-Forb
Uvularia grandiflora	BELLWORT	5	5	Nt P-Forb
Viburnum opulus var. americanum	HIGHBUSH CRANBERRY	5	-3	Nt Shrub
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb
Vitis aestivalis	SUMMER GRAPE	6	3	Nt W-Vine
Russ Forest				
Acer rubrum	RED MAPLE	1	0	Nt Tree
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb
Carex jamesii	JAMES' SEDGE	8	5	Nt P-Sedge
Celtis occidentalis	HACKBERRY	5	1	Nt Tree
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb
Claytonia virginica	SPRING-BEAUTY	4	3	Nt P-Forb
Dentaria laciniata	CUT-LEAVED TOOTHWORT	5	3	Nt P-Forb
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb
Dicentra canadensis	SQUIRREL CORN	7	5	Nt P-Forb
Euonymus obovata	RUNNING STRAWBERRY BUSH	5	5	Nt Shrub
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb
Geum canadense	WHITE AVENS	1	0	Nt P-Forb
Impatiens capensis	SPOTTED TOUCH-ME-NOT	2	-3	Nt A-Forb
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub
Maianthemum canadense	CANADA MAYFLOWER	4	0	Nt P-Forb
Monotropa uniflora	INDIAN PIPE	5	3	Nt P-Forb
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine
Phytolacca americana	POKEWEED	2	1	Nt P-Forb
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree
Quercus alba	WHITE OAK	5	3	Nt Tree
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree

Appendix 1. (cont'd)

Scientific Name	Common Name	C	W	PHYS
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb
Viola rostrata	LONG-SPURRED VIOLET	6	3	Nt P-Forb
Viola striata	CREAM VIOLET	5	-3	Nt P-Forb
Shiawassee				
Acer negundo	BOX ELDER	0	-2	Nt Tree
Acer saccharinum	SILVER MAPLE	2	-3	Nt Tree
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb
Allium canadense	WILD GARLIC	4	3	Nt P-Forb
Anemone canadensis	CANADA ANEMONE	4	-3	Nt P-Forb
Arisaema dracontium	GREEN DRAGON	8	-3	Nt P-Forb
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb
Aster lanceolatus	EASTERN LINED ASTER	2	-3	Nt P-Forb
Aster ontarionis	ONTARIO ASTER	6	0	Nt P-Forb
Boehmeria cylindrica	FALSE NETTLE	5	-5	Nt P-Forb
BRASSICA NIGRA	BLACK MUSTARD	*	5	Ad A-Forb
Carex blanda	SEDGE	1	0	Nt P-Sedge
Carex grayi	SEDGE	6	-4	Nt P-Sedge
Carex grisea	SEDGE	3	-3	Nt P-Sedge
Celtis occidentalis	HACKBERRY	5	1	Nt Tree
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb
Crataegus punctata	DOTTED HAWTHORN	1	5	Nt Tree
Dioscorea villosa	WILD YAM	4	1	Nt P-Forb
Elymus villosus	SILKY WILD-RYE	5	3	Nt P-Grass
Elymus virginicus	VIRGINIA WILD-RYE	4	-2	Nt P-Grass
Erigeron philadelphicus	MARSH FLEABANE	2	-3	Nt P-Forb
Eupatorium rugosum	WHITE SNAKEROOT	4	3	Nt P-Forb
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb
Geum canadense	WHITE AVENS	1	0	Nt P-Forb
Impatiens capensis	SPOTTED TOUCH-ME-NOT	2	-3	Nt A-Forb
Juglans nigra	BLACK WALNUT	5	3	Nt Tree
Laportea canadensis	WOOD NETTLE	4	-3	Nt P-Forb
Lobelia siphilitica	GREAT BLUE LOBELIA	4	-4	Nt P-Forb
LONICERA MAACKII	AMUR HONEYSUCKLE	*	5	Ad Shrub
Lysimachia ciliata	FRINGED LOOSESTRIFE	4	-3	Nt P-Forb
LYSIMACHIA NUMMULARIA	MONEYWORT	*	-4	Ad P-Forb
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb
Polygonatum biflorum	SOLOMON-SEAL	4	3	Nt P-Forb
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree
Quercus velutina	BLACK OAK	6	5	Nt Tree
Ranunculus hispidus	SWAMP BUTTERCUP	5	0	Nt P-Forb
Ranunculus recurvatus	HOOKED CROWFOOT	5	-3	Nt A-Forb
Ribes americanum	WILD BLACK CURRANT	6	-3	Nt Shrub
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub

Appendix 1. (cont'd)

Scientific Name	Common Name	C	W	PHYS
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub
Sambucus canadensis	ELDERBERRY	3	-2	Nt Shrub
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb
Solidago gigantea	LATE GOLDENROD	3	-3	Nt P-Forb
TARAXACUM OFFICINALE	COMMON DANDELION	*	3	Ad P-Forb
Teucrium canadense	WOOD SAGE	4	-2	Nt P-Forb
Thalictrum dasycarpum	PURPLE MEADOW-RUE	3	-2	Nt P-Forb
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree
Urtica dioica	NETTLE	1	-1	Nt P-Forb
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine

APPENDIX 2

Appendix 2. Inventories of species observed in sampling quadrats from each site during each sampling date with Floristic Quality Assessment data. Scientific names of non-native species are shown in all capitals. Additional information for each species includes the coefficient of conservatism (C), the coefficient of wetness (W), the growth form and life cycle of the species (PHYS), the number of quadrats it was observed in (FRQ), the sum of cover from all quadrats (COV), the relative frequency (RFRQ), the relative cover (RCOV) and the relative importance value (RIV). Abbreviations shown under physiognomy indicate: Nt = native, Ad = adventive, A = annual, B = biennial, P = perennial, H = herbaceous, and W = woody.

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
BOX WOODLOT									
Fall 2003									
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	11	120	42.3	64.9	53.6
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	9	41	34.6	22.2	28.4
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	2	15	7.7	8.1	7.9
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	2	6	7.7	3.2	5.5
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	1	2	3.8	1.1	2.5
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	3.8	0.5	2.2
Fall 2004									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	17	83	40.5	43.9	42.2
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	11	61	26.2	32.3	29.2
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	2	18	4.8	9.5	7.1
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	4	9	9.5	4.8	7.1
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	3	12	7.1	6.3	6.7
Quercus macrocarpa	BUR OAK	5	1	Nt Tree	1	2	2.4	1.1	1.7
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	1	1	2.4	0.5	1.5
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	2.4	0.5	1.5
Acer saccharinum	SILVER MAPLE	2	-3	Nt Tree	1	1	2.4	0.5	1.5
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	1	1	2.4	0.5	1.5
Fall 2005									
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	8	65	42.1	69.9	56
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	4	12	21.1	12.9	17
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	1	10	5.3	10.8	8
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	2	2	10.5	2.2	6.3

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	1	1	5.3	1.1	3.2
Spring 2003									
Quercus alba	WHITE OAK	5	3	Nt Tree	1	1	5.3	1.1	3.2
Sambucus racemosa	RED-BERRIED ELDER	3	2	Nt Shrub	1	1	5.3	1.1	3.2
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	1	1	5.3	1.1	3.2
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	16	316	30.2	42.8	36.5
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	14	186	26.4	25.2	25.8
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	7	164	13.2	22.2	17.7
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	6	13	11.3	1.8	6.5
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	20	3.8	2.7	3.2
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	2	14	3.8	1.9	2.8
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	2	14	3.8	1.9	2.8
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	1	5	1.9	0.7	1.3
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	1	5	1.9	0.7	1.3
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	1.9	0.1	1
Erythronium americanum	YELLOW TROUT LILY	5	5	Nt P-Forb	1	1	1.9	0.1	1
Spring 2004									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	18	394	34.6	55	44.8
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	7	166	13.5	23.2	18.3
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	10	96	19.2	13.4	16.3
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	5	16	9.6	2.2	5.9
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	3	20	5.8	2.8	4.3
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	2	12	3.8	1.7	2.8
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	2	3.8	0.3	2.1
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	1	6	1.9	0.8	1.4
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	1	2	1.9	0.3	1.1
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	1	1	1.9	0.1	1
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	1.9	0.1	1
Acer saccharinum	SILVER MAPLE	2	-3	Nt Tree	1	1	1.9	0.1	1

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	C	W	PHYS	FRQ	COV	RFRQ	RCOV	RIV
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	19	245	32.8	48.7	40.7
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	10	111	17.2	22.1	19.7
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	6	95	10.3	18.9	14.6
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	12	12	20.7	2.4	11.5
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	2	22	3.4	4.4	3.9
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	3	4	5.2	0.8	3
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	2	5	3.4	1	2.2
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	3	3.4	0.6	2
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	1	5	1.7	1	1.4
Acer saccharinum	SILVER MAPLE	2	-3	Nt Tree	1	1	1.7	0.2	1
FERNWOOD									
Fall 2003									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	20	135	27.4	44	35.7
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	7	17	9.6	5.5	7.6
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	3	26	4.1	8.5	6.3
Hystrix patula	BOTTLEBRUSH GRASS	5	5	Nt P-Grass	7	7	9.6	2.3	5.9
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	5	11	6.8	3.6	5.2
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	3	13	4.1	4.2	4.2
Asimina triloba	PAWPAW	9	0	Nt Tree	1	20	1.4	6.5	3.9
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	3	11	4.1	3.6	3.8
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	3	9	4.1	2.9	3.5
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree	3	5	4.1	1.6	2.9
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	3	3	4.1	1	2.5
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	1	10	1.4	3.3	2.3
Eupatorium rugosum	WHITE SNAKEROOT	4	3	Nt P-Forb	2	6	2.7	2	2.3
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	2	6	2.7	2	2.3
Fraxinus americana	WHITE ASH	5	3	Nt Tree	1	10	1.4	3.3	2.3
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	2	4	2.7	1.3	2
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	2	4	2.7	1.3	2

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Viola sororia	COMMON BLUE VIOLET	1	1	Nt P-Forb	2	3	2.7	1	1.9
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	1	5	1.4	1.6	1.5
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	1	1	1.4	0.3	0.8
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	1.4	0.3	0.8
Fall 2004									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	13	23	17.8	8.9	13.4
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	10	18	13.7	7	10.4
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	3	41	4.1	16	10
Asimina triloba	PAWPAW	9	0	Nt Tree	2	38	2.7	14.8	8.8
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	1	40	1.4	15.6	8.5
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	4	26	5.5	10.1	7.8
Hystrix patula	BOTTLEBRUSH GRASS	5	5	Nt P-Grass	7	7	9.6	2.7	6.2
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	2	21	2.7	8.2	5.5
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	6	6	8.2	2.3	5.3
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	4	4	5.5	1.6	3.5
Viola sororia	COMMON BLUE VIOLET	1	1	Nt P-Forb	3	6	4.1	2.3	3.2
Carex blanda	SEDGE	1	0	Nt P-Sedge	3	4	4.1	1.6	2.8
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	3	3	4.1	1.2	2.6
Eupatorium rugosum	WHITE SNAKEROOT	4	3	Nt P-Forb	1	6	1.4	2.3	1.9
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	2	2	2.7	0.8	1.8
Juglans nigra	BLACK WALNUT	5	3	Nt Tree	1	3	1.4	1.2	1.3
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine	1	2	1.4	0.8	1.1
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	1	1	1.4	0.4	0.9
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	1	1	1.4	0.4	0.9
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	1	1.4	0.4	0.9
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	1.4	0.4	0.9
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	1	1	1.4	0.4	0.9
Galium asprellum	ROUGH BEDSTRAW	5	-5	Nt P-Forb	1	1	1.4	0.4	0.9
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	1	1	1.4	0.4	0.9
Fall 2005									

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	20	67	24.7	35.6	30.2
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	7	23	8.6	12.2	10.4
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	7	18	8.6	9.6	9.1
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	9	10	11.1	5.3	8.2
Hystrix patula	BOTTLEBRUSH GRASS	5	5	Nt P-Grass	8	8	9.9	4.3	7.1
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	4	6	4.9	3.2	4.1
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine	3	7	3.7	3.7	3.7
Fraxinus americana	WHITE ASH	5	3	Nt Tree	1	10	1.2	5.3	3.3
Viola sororia	COMMON BLUE VIOLET	1	1	Nt P-Forb	3	5	3.7	2.7	3.2
Asimina triloba	PAWPAW	9	0	Nt Tree	2	5	2.5	2.7	2.6
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	1	6	1.2	3.2	2.2
Carex blanda	SEDGE	1	0	Nt P-Sedge	2	3	2.5	1.6	2
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	2	2	2.5	1.1	1.8
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	2	2.5	1.1	1.8
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	1	4	1.2	2.1	1.7
Polygonatum biflorum	SOLOMON-SEAL	4	3	Nt P-Forb	1	3	1.2	1.6	1.4
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree	1	2	1.2	1.1	1.1
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	1	1	1.2	0.5	0.9
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	1	1.2	0.5	0.9
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	1	1	1.2	0.5	0.9
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	1.2	0.5	0.9
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	1	1	1.2	0.5	0.9
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	1	1	1.2	0.5	0.9
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	1	1	1.2	0.5	0.9
Spring 2003									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	20	793	15.7	50.6	33.2
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	15	174	11.8	11.1	11.5
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	12	96	9.4	6.1	7.8
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	9	59	7.1	3.8	5.4
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	4	82	3.1	5.2	4.2

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	5	67	3.9	4.3	4.1
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	8	19	6.3	1.2	3.8
Hystrix patula	BOTTLEBRUSH GRASS	5	5	Nt P-Grass	8	8	6.3	0.5	3.4
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	4	52	3.1	3.3	3.2
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	4	36	3.1	2.3	2.7
Sassafras albidum	SASSAFRAS	5	3	Nt Tree	2	50	1.6	3.2	2.4
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	4	20	3.1	1.3	2.2
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	4	16	3.1	1	2.1
Viola sororia	COMMON BLUE VIOLET	1	1	Nt P-Forb	4	11	3.1	0.7	1.9
Hydrophyllum appendiculatum	GREAT WATERLEAF	7	5	Nt P-Forb	3	23	2.4	1.5	1.9
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	2	15	1.6	1	1.3
Eupatorium rugosum	WHITE SNAKEROOT	4	3	Nt P-Forb	3	4	2.4	0.3	1.3
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	2	9	1.6	0.6	1.1
Polygonatum biflorum	SOLOMON-SEAL	4	3	Nt P-Forb	2	3	1.6	0.2	0.9
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	1	8	0.8	0.5	0.6
Fraxinus americana	WHITE ASH	5	3	Nt Tree	1	5	0.8	0.3	0.6
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	1	3	0.8	0.2	0.5
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	2	0.8	0.1	0.5
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	1	2	0.8	0.1	0.5
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	1	4	0.8	0.3	0.5
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	1	1	0.8	0.1	0.4
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	1	1	0.8	0.1	0.4
Ranunculus abortivus	SMALL-FLOWERED	0	-2	Nt A-Forb	1	1	0.8	0.1	0.4
Quercus alba	WHITE OAK	5	3	Nt Tree	1	1	0.8	0.1	0.4
Euonymus obovata	RUNNING STRAWBERRY	5	5	Nt Shrub	1	1	0.8	0.1	0.4
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine	1	1	0.8	0.1	0.4
Spring 2004									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	20	999	13.7	62.3	38
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	15	108	10.3	6.7	8.5
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	12	57	8.2	3.6	5.9

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Hystrix patula	BOTTLEBRUSH GRASS	5	5	Nt P-Grass	11	13	7.5	0.8	4.2
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	9	31	6.2	1.9	4
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	5	68	3.4	4.2	3.8
Viola sororia	COMMON BLUE VIOLET	1	1	Nt P-Forb	8	16	5.5	1	3.2
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	5	39	3.4	2.4	2.9
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	6	16	4.1	1	2.6
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	2	45	1.4	2.8	2.1
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	5	8	3.4	0.5	2
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	3	20	2.1	1.2	1.7
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	4	8	2.7	0.5	1.6
Asimina triloba	PAWPAW	9	0	Nt Tree	2	28	1.4	1.7	1.6
Fraxinus americana	WHITE ASH	5	3	Nt Tree	1	40	0.7	2.5	1.6
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	3	14	2.1	0.9	1.5
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	4	4	2.7	0.2	1.5
Polygonatum biflorum	SOLOMON-SEAL	4	3	Nt P-Forb	3	12	2.1	0.7	1.4
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	3	9	2.1	0.6	1.3
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	3	7	2.1	0.4	1.2
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	1	20	0.7	1.2	1
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	8	1.4	0.5	0.9
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine	2	5	1.4	0.3	0.8
Ranunculus abortivus	SMALL-FLOWERED	0	-2	Nt A-Forb	2	2	1.4	0.1	0.7
Dentaria laciniata	CUT-LEAVED TOOTHWORT	5	3	Nt P-Forb	2	2	1.4	0.1	0.7
Hydrophyllum appendiculatum	GREAT WATERLEAF	7	5	Nt P-Forb	1	7	0.7	0.4	0.6
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree	1	2	0.7	0.1	0.4
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	1	1	0.7	0.1	0.4
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	2	0.7	0.1	0.4
Viola canadensis	CANADA VIOLET	5	5	Nt P-Forb	1	1	0.7	0.1	0.4
Trillium grandiflorum	COMMON TRILLIUM	5	5	Nt P-Forb	1	1	0.7	0.1	0.4
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb	1	1	0.7	0.1	0.4

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	0.7	0.1	0.4
LAMIUM PURPUREUM	PURPLE DEAD-NETTLE	*	5	Ad A-Forb	1	1	0.7	0.1	0.4
Eupatorium rugosum	WHITE SNAKEROOT	4	3	Nt P-Forb	1	1	0.7	0.1	0.4
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	2	0.7	0.1	0.4
Aster cordifolius	HEART-LEAVED ASTER	4	5	Nt P-Forb	1	2	0.7	0.1	0.4
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	1	2	0.7	0.1	0.4
Spring 2005									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	20	753	13.4	57.4	35.4
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	15	155	10.1	11.8	10.9
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	9	50	6	3.8	4.9
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	11	21	7.4	1.6	4.5
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	8	21	5.4	1.6	3.5
Hystrix patula	BOTTLEBRUSH GRASS	5	5	Nt P-Grass	9	10	6	0.8	3.4
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	4	48	2.7	3.7	3.2
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	7	16	4.7	1.2	3
Viola sororia	COMMON BLUE VIOLET	1	1	Nt P-Forb	7	17	4.7	1.3	3
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	5	27	3.4	2.1	2.7
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	5	17	3.4	1.3	2.3
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	4	21	2.7	1.6	2.1
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	4	13	2.7	1	1.8
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	3	19	2	1.4	1.7
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	4	9	2.7	0.7	1.7
Dentaria laciniata	CUT-LEAVED TOOTHWORT	5	3	Nt P-Forb	4	5	2.7	0.4	1.5
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	3	5	2	0.4	1.2
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	3	3	2	0.2	1.1
Hydrophyllum appendiculatum	GREAT WATERLEAF	7	5	Nt P-Forb	2	12	1.3	0.9	1.1
Asimina triloba	PAWPAW	9	0	Nt Tree	1	20	0.7	1.5	1.1
Carex blanda	SEDGE	1	0	Nt P-Sedge	2	5	1.3	0.4	0.9
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	2	5	1.3	0.4	0.9
LAMIUM PURPUREUM	PURPLE DEAD-NETTLE	*	5	Ad A-Forb	2	3	1.3	0.2	0.8
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	1	12	0.7	0.9	0.8

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	4	1.3	0.3	0.8
Fraxinus americana	WHITE ASH	5	3	Nt Tree	1	10	0.7	0.8	0.7
Polygonatum biflorum	SOLOMON-SEAL	4	3	Nt P-Forb	1	8	0.7	0.6	0.6
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine	1	4	0.7	0.3	0.5
Eupatorium rugosum	WHITE SNAKEROOT	4	3	Nt P-Forb	1	5	0.7	0.4	0.5
Ranunculus abortivus	SMALL-FLOWERED	0	-2	Nt A-Forb	1	1	0.7	0.1	0.4
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree	1	3	0.7	0.2	0.4
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	1	1	0.7	0.1	0.4
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	1	1	0.7	0.1	0.4
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb	1	2	0.7	0.2	0.4
Trillium grandiflorum	COMMON TRILLIUM	5	5	Nt P-Forb	1	2	0.7	0.2	0.4
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	2	0.7	0.2	0.4
Glyceria striata	FOWL MANNA GRASS	4	-5	Nt P-Grass	1	1	0.7	0.1	0.4
FORT CUSTER									
Fall 2003									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	8	73	16.7	44.8	30.7
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	13	26	27.1	16	21.5
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	12	24	25	14.7	19.9
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	6	30	12.5	18.4	15.5
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	5	5	10.4	3.1	6.7
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	1	2	2.1	1.2	1.7
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	1	1	2.1	0.6	1.3
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	1	1	2.1	0.6	1.3
Quercus velutina	BLACK OAK	6	5	Nt Tree	1	1	2.1	0.6	1.3
Fall 2004									
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	19	184	13	22.2	17.6
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb	13	84	8.9	10.1	9.5
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	8	78	5.5	9.4	7.4
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	12	48	8.2	5.8	7

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	7	55	4.8	6.6	5.7
Amphicarpaea bracteata	HOG-PEANUT	5	0	Nt A-Forb	6	42	4.1	5.1	4.6
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	8	30	5.5	3.6	4.5
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	8	13	5.5	1.6	3.5
Quercus alba	WHITE OAK	5	3	Nt Tree	4	27	2.7	3.3	3
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	3	32	2.1	3.9	3
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb	4	19	2.7	2.3	2.5
Galium concinnum	SHINING BEDSTRAW	5	3	Nt P-Forb	5	11	3.4	1.3	2.4
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	4	9	2.7	1.1	1.9
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	1	25	0.7	3	1.9
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb	2	19	1.4	2.3	1.8
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	2	14	1.4	1.7	1.5
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	2	13	1.4	1.6	1.5
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	3	6	2.1	0.7	1.4
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	2	12	1.4	1.4	1.4
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	3	5	2.1	0.6	1.3
Urtica dioica	NETTLE	1	-1	Nt P-Forb	1	15	0.7	1.8	1.2
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	2	6	1.4	0.7	1
Viola canadensis	CANADA VIOLET	5	5	Nt P-Forb	2	5	1.4	0.6	1
Smilax lasioneura	CARRION-FLOWER	5	5	Nt W-Vine	1	9	0.7	1.1	0.9
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	3	1.4	0.4	0.9
Vitis aestivalis	SUMMER GRAPE	6	3	Nt W-Vine	2	4	1.4	0.5	0.9
Amelanchier laevis	SMOOTH SHADBUSH	4	5	Nt Tree	1	9	0.7	1.1	0.9
Elymus villosus	SILKY WILD-RYE	5	3	Nt P-Grass	2	2	1.4	0.2	0.8
Festuca subverticillata	NODDING FESCUE	5	2	Nt P-Grass	1	8	0.7	1	0.8
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	2	2	1.4	0.2	0.8
Acer rubrum	RED MAPLE	1	0	Nt Tree	1	5	0.7	0.6	0.6
Galium pilosum	HAIRY BEDSTRAW	6	5	Nt P-Forb	1	5	0.7	0.6	0.6
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	1	5	0.7	0.6	0.6

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Phryma leptostachya	LOPSEED	4	5	Nt P-Forb	1	4	0.7	0.5	0.6
Sambucus racemosa	RED-BERRIED ELDER	3	2	Nt Shrub	1	3	0.7	0.4	0.5
Sassafras albidum	SASSAFRAS	5	3	Nt Tree	1	3	0.7	0.4	0.5
Carex cephalophora	SEDGE	3	3	Nt P-Sedge	1	2	0.7	0.2	0.5
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	1	2	0.7	0.2	0.5
RUMEX OBTUSIFOLIUS	BITTER DOCK	*	-3	Ad P-Forb	1	3	0.7	0.4	0.5
Cinna arundinacea	WOOD REEDGRASS	7	-3	Nt P-Grass	1	2	0.7	0.2	0.5
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	1	2	0.7	0.2	0.5
Aster lanceolatus	EASTERN LINED ASTER	2	-3	Nt P-Forb	1	2	0.7	0.2	0.5
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	1	1	0.7	0.1	0.4
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	1	1	0.7	0.1	0.4
Fall 2005									
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	20	81	10.9	11.4	11.1
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb	14	47	7.6	6.6	7.1
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	11	59	6	8.3	7.1
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	12	45	6.5	6.3	6.4
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	12	38	6.5	5.4	5.9
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	6	55	3.3	7.8	5.5
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	11	28	6	3.9	5
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	4	52	2.2	7.3	4.8
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	10	19	5.4	2.7	4.1
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	5	35	2.7	4.9	3.8
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	8	20	4.3	2.8	3.6
Amphicarpaea bracteata	HOG-PEANUT	5	0	Nt A-Forb	5	24	2.7	3.4	3.1
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	5	22	2.7	3.1	2.9
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	5	19	2.7	2.7	2.7
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb	4	17	2.2	2.4	2.3
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	5	14	2.7	2	2.3
Quercus alba	WHITE OAK	5	3	Nt Tree	2	21	1.1	3	2
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	5	6	2.7	0.8	1.8

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Amelanchier laevis	SMOOTH SHADBUSH	4	5	Nt Tree	2	17	1.1	2.4	1.7
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	4	8	2.2	1.1	1.7
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb	4	4	2.2	0.6	1.4
Acer rubrum	RED MAPLE	1	0	Nt Tree	3	5	1.6	0.7	1.2
RUMEX OBTUSIFOLIUS	BITTER DOCK	*	-3	Ad P-Forb	2	10	1.1	1.4	1.2
Vitis aestivalis	SUMMER GRAPE	6	3	Nt W-Vine	2	9	1.1	1.3	1.2
Urtica dioica	NETTLE	1	-1	Nt P-Forb	1	10	0.5	1.4	1
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	2	3	1.1	0.4	0.8
Desmodium glutinosum	CLUSTERED-LEAVED TICK-TREEFOIL	5	5	Nt P-Forb	1	8	0.5	1.1	0.8
Galium pilosum	HAIRY BEDSTRAW	6	5	Nt P-Forb	1	6	0.5	0.8	0.7
Elymus villosus	SILKY WILD-RYE	5	3	Nt P-Grass	2	2	1.1	0.3	0.7
Aster lanceolatus	EASTERN LINED ASTER	2	-3	Nt P-Forb	2	2	1.1	0.3	0.7
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	2	2	1.1	0.3	0.7
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb	1	5	0.5	0.7	0.6
Senecio obovatus	ROUND-LEAVED	10	4	Nt P-Forb	1	3	0.5	0.4	0.5
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	1	2	0.5	0.3	0.4
Phryma leptostachya	LOPSEED	4	5	Nt P-Forb	1	2	0.5	0.3	0.4
Smilax lasioneura	CARRION-FLOWER	5	5	Nt W-Vine	1	2	0.5	0.3	0.4
Cinna arundinacea	WOOD REEDGRASS	7	-3	Nt P-Grass	1	1	0.5	0.1	0.3
Carex cephalophora	SEDGE	3	3	Nt P-Sedge	1	1	0.5	0.1	0.3
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	1	1	0.5	0.1	0.3
Sambucus racemosa	RED-BERRIED ELDER	3	2	Nt Shrub	1	1	0.5	0.1	0.3
RHAMNUS CATHARTICA	COMMON BUCKTHORN	*	3	Ad Tree	1	1	0.5	0.1	0.3
Festuca subverticillata	NODDING FESCUE	5	2	Nt P-Grass	1	1	0.5	0.1	0.3
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	1	1	0.5	0.1	0.3
Spring 2003									
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	19	269	12.8	16.7	14.7
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	18	235	12.2	14.6	13.4
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	15	176	10.1	10.9	10.5

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	7	200	4.7	12.4	8.6
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb	14	83	9.5	5.1	7.3
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	6	123	4.1	7.6	5.8
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	9	62	6.1	3.8	5
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	6	84	4.1	5.2	4.6
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb	7	34	4.7	2.1	3.4
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	3	77	2	4.8	3.4
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	5	40	3.4	2.5	2.9
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	4	30	2.7	1.9	2.3
Quercus alba	WHITE OAK	5	3	Nt Tree	4	22	2.7	1.4	2
Elymus villosus	SILKY WILD-RYE	5	3	Nt P-Grass	4	4	2.7	0.2	1.5
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	2	27	1.4	1.7	1.5
Amphicarpaea bracteata	HOG-PEANUT	5	0	Nt A-Forb	3	14	2	0.9	1.4
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	3	7	2	0.4	1.2
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	2	18	1.4	1.1	1.2
BERBERIS THUNBERGII	JAPANESE BARBERRY	*	4	Ad Shrub	1	25	0.7	1.5	1.1
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	2	11	1.4	0.7	1
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	3	1.4	0.2	0.8
RUMEX OBTUSIFOLIUS	BITTER DOCK	*	-3	Ad P-Forb	1	15	0.7	0.9	0.8
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb	2	4	1.4	0.2	0.8
Amelanchier laevis	SMOOTH SHADBUSH	4	5	Nt Tree	1	12	0.7	0.7	0.7
Onoclea sensibilis	SENSITIVE FERN	2	-3	Nt Fern	1	10	0.7	0.6	0.6
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	1	10	0.7	0.6	0.6
Urtica dioica	NETTLE	1	-1	Nt P-Forb	1	5	0.7	0.3	0.5
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	1	5	0.7	0.3	0.5
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb	1	5	0.7	0.3	0.5
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	1	2	0.7	0.1	0.4
Galium pilosum	HAIRY BEDSTRAW	6	5	Nt P-Forb	1	2	0.7	0.1	0.4
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	1	1	0.7	0.1	0.4

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Spring 2004									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	11	315	5.1	21.1	13.1
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	19	168	8.8	11.3	10
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	15	107	6.9	7.2	7
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	16	97	7.4	6.5	6.9
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb	15	78	6.9	5.2	6.1
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	15	58	6.9	3.9	5.4
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb	17	33	7.8	2.2	5
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	4	113	1.8	7.6	4.7
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	13	25	6	1.7	3.8
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	6	52	2.8	3.5	3.1
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	7	37	3.2	2.5	2.9
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	5	46	2.3	3.1	2.7
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	5	47	2.3	3.2	2.7
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb	4	50	1.8	3.4	2.6
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb	7	25	3.2	1.7	2.5
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	4	40	1.8	2.7	2.3
Quercus alba	WHITE OAK	5	3	Nt Tree	4	27	1.8	1.8	1.8
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	4	19	1.8	1.3	1.6
Amphicarpaea bracteata	HOG-PEANUT	5	0	Nt A-Forb	5	13	2.3	0.9	1.6
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	5	8	2.3	0.5	1.4
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	2	25	0.9	1.7	1.3
Acer rubrum	RED MAPLE	1	0	Nt Tree	4	7	1.8	0.5	1.2
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	2	22	0.9	1.5	1.2
Festuca subverticillata	NODDING FESCUE	5	2	Nt P-Grass	4	6	1.8	0.4	1.1
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	3	9	1.4	0.6	1
RUMEX OBTUSIFOLIUS	BITTER DOCK	*	-3	Ad P-Forb	2	13	0.9	0.9	0.9
Impatiens pallida	PALE TOUCH-ME-NOT	6	-3	Nt A-Forb	2	3	0.9	0.2	0.6
Onoclea sensibilis	SENSITIVE FERN	2	-3	Nt Fern	2	5	0.9	0.3	0.6

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	C	W	PHYS	FRQ	COV	RFRQ	RCOV	RIV
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	2	4	0.9	0.3	0.6
Vitis aestivalis	SUMMER GRAPE	6	3	Nt W-Vine	2	3	0.9	0.2	0.6
Amelanchier laevis	SMOOTH SHADBUSH	4	5	Nt Tree	1	8	0.5	0.5	0.5
Smilax lasioneura	CARRION-FLOWER	5	5	Nt W-Vine	1	7	0.5	0.5	0.5
Phlox divaricata	WOODLAND PHLOX	5	3	Nt P-Forb	1	4	0.5	0.3	0.4
BERBERIS THUNBERGII	JAPANESE BARBERRY	*	4	Ad Shrub	1	4	0.5	0.3	0.4
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	1	1	0.5	0.1	0.3
Aster lanceolatus	EASTERN LINED ASTER	2	-3	Nt P-Forb	1	1	0.5	0.1	0.3
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	1	3	0.5	0.2	0.3
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	1	2	0.5	0.1	0.3
Cinna arundinacea	WOOD REEDGRASS	7	-3	Nt P-Grass	1	2	0.5	0.1	0.3
Galium pilosum	HAIRY BEDSTRAW	6	5	Nt P-Forb	1	1	0.5	0.1	0.3
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	1	3	0.5	0.2	0.3
Spring 2005									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	11	197	4.7	16	10.3
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	19	121	8.1	9.8	9
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	19	115	8.1	9.3	8.7
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb	19	100	8.1	8.1	8.1
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	14	86	6	7	6.5
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	9	90	3.8	7.3	5.6
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb	17	42	7.2	3.4	5.3
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	13	49	5.5	4	4.8
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	10	43	4.3	3.5	3.9
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	7	60	3	4.9	3.9
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	13	19	5.5	1.5	3.5
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	10	24	4.3	1.9	3.1
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	7	35	3	2.8	2.9
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	8	21	3.4	1.7	2.6
Amphicarpaea bracteata	HOG-PEANUT	5	0	Nt A-Forb	5	19	2.1	1.5	1.8
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb	4	23	1.7	1.9	1.8

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	4	19	1.7	1.5	1.6
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	3	23	1.3	1.9	1.6
Quercus alba	WHITE OAK	5	3	Nt Tree	3	19	1.3	1.5	1.4
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	4	13	1.7	1.1	1.4
Amelanchier laevis	SMOOTH SHADBUSH	4	5	Nt Tree	2	19	0.9	1.5	1.2
Phryma leptostachya	LOPSEED	4	5	Nt P-Forb	4	6	1.7	0.5	1.1
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	2	11	0.9	0.9	0.9
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb	2	11	0.9	0.9	0.9
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	3	4	1.3	0.3	0.8
Onoclea sensibilis	SENSITIVE FERN	2	-3	Nt Fern	1	10	0.4	0.8	0.6
Vitis aestivalis	SUMMER GRAPE	6	3	Nt W-Vine	2	5	0.9	0.4	0.6
Elymus villosus	SILKY WILD-RYE	5	3	Nt P-Grass	2	3	0.9	0.2	0.5
Impatiens pallida	PALE TOUCH-ME-NOT	6	-3	Nt A-Forb	2	2	0.9	0.2	0.5
Cinna arundinacea	WOOD REEDGRASS	7	-3	Nt P-Grass	2	2	0.9	0.2	0.5
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	2	3	0.9	0.2	0.5
Smilax lasioneura	CARRION-FLOWER	5	5	Nt W-Vine	1	8	0.4	0.6	0.5
Galium pilosum	HAIRY BEDSTRAW	6	5	Nt P-Forb	1	5	0.4	0.4	0.4
Sambucus racemosa	RED-BERRIED ELDER	3	2	Nt Shrub	1	5	0.4	0.4	0.4
RUMEX OBTUSIFOLIUS	BITTER DOCK	*	-3	Ad P-Forb	1	4	0.4	0.3	0.4
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	1	5	0.4	0.4	0.4
Festuca subverticillata	NODDING FESCUE	5	2	Nt P-Grass	1	2	0.4	0.2	0.3
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	1	1	0.4	0.1	0.3
Acer rubrum	RED MAPLE	1	0	Nt Tree	1	3	0.4	0.2	0.3
STELLARIA MEDIA	COMMON CHICKWEED	*	3	Ad A-Forb	1	1	0.4	0.1	0.3
Aster lanceolatus	EASTERN LINED ASTER	2	-3	Nt P-Forb	1	2	0.4	0.2	0.3
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	1	1	0.4	0.1	0.3
Carex cephalophora	SEDGE	3	3	Nt P-Sedge	1	1	0.4	0.1	0.3
IVES ROAD									
Fall 2003									
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	13	255	26.5	53.1	39.8

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	7	67	14.3	14	14.1
Laportea canadensis	WOOD NETTLE	4	-3	Nt P-Forb	4	72	8.2	15	11.6
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	7	19	14.3	4	9.1
Viola striata	CREAM VIOLET	5	-3	Nt P-Forb	3	33	6.1	6.9	6.5
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	5	5	10.2	1	5.6
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	3	8	6.1	1.7	3.9
Carex grisea	SEDGE	3	-3	Nt P-Sedge	2	8	4.1	1.7	2.9
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	3	4.1	0.6	2.4
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	1	5	2	1	1.5
Fraxinus americana	WHITE ASH	5	3	Nt Tree	1	3	2	0.6	1.3
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	1	2	2	0.4	1.2
Fall 2004									
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	14	143	14.4	44.8	29.6
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	18	22	18.6	6.9	12.7
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	9	21	9.3	6.6	7.9
Laportea canadensis	WOOD NETTLE	4	-3	Nt P-Forb	4	25	4.1	7.8	6
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	6	10	6.2	3.1	4.7
Viola striata	CREAM VIOLET	5	-3	Nt P-Forb	3	16	3.1	5	4.1
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	4	12	4.1	3.8	3.9
Carex grisea	SEDGE	3	-3	Nt P-Sedge	3	9	3.1	2.8	3
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	3	7	3.1	2.2	2.6
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	3	6	3.1	1.9	2.5
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	2	8	2.1	2.5	2.3
Allium tricoccum	WILD LEEK	5	2	Nt P-Forb	3	4	3.1	1.3	2.2
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	3	3	3.1	0.9	2
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	5	2.1	1.6	1.8
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	2	5	2.1	1.6	1.8
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	2	5	2.1	1.6	1.8
Carex hirtifolia	SEDGE	5	5	Nt P-Sedge	2	3	2.1	0.9	1.5

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Fraxinus americana	WHITE ASH	5	3	Nt Tree	2	2	2.1	0.6	1.3
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	2	2	2.1	0.6	1.3
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb	2	2	2.1	0.6	1.3
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	1	2	1	0.6	0.8
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	1	1	1	0.3	0.7
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine	1	1	1	0.3	0.7
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	1	1	1	0.3	0.7
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	1	0.3	0.7
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	1	1	1	0.3	0.7
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	1	1	1	0.3	0.7
Sambucus racemosa	RED-BERRIED ELDER	3	2	Nt Shrub	1	1	1	0.3	0.7
Spring 2003									
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	15	350	11.6	31.9	21.8
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	18	135	14	12.3	13.1
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	15	124	11.6	11.3	11.5
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	11	131	8.5	12	10.2
Laportea canadensis	WOOD NETTLE	4	-3	Nt P-Forb	5	95	3.9	8.7	6.3
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	10	42	7.8	3.8	5.8
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	11	15	8.5	1.4	4.9
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	4	64	3.1	5.8	4.5
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	5	43	3.9	3.9	3.9
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	5	38	3.9	3.5	3.7
Carex grisea	SEDGE	3	-3	Nt P-Sedge	5	5	3.9	0.5	2.2
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	4	12	3.1	1.1	2.1
Viola striata	CREAM VIOLET	5	-3	Nt P-Forb	3	8	2.3	0.7	1.5
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	3	5	2.3	0.5	1.4
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	2	12	1.6	1.1	1.3
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	3	3	2.3	0.3	1.3
Fraxinus americana	WHITE ASH	5	3	Nt Tree	1	4	0.8	0.4	0.6
Agrimonia pubescens	SOFT AGRIMONY	5	5	Nt P-Forb	1	2	0.8	0.2	0.5
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	1	1	0.8	0.1	0.4

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	C	W	PHYS	FRQ	COV	RFRQ	RCOV	RIV
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	1	1	0.8	0.1	0.4
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	1	1	0.8	0.1	0.4
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb	1	1	0.8	0.1	0.4
Carex hirtifolia	SEDGE	5	5	Nt P-Sedge	1	1	0.8	0.1	0.4
Allium tricoccum	WILD LEEK	5	2	Nt P-Forb	1	1	0.8	0.1	0.4
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	1	1	0.8	0.1	0.4
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	0.8	0.1	0.4
Spring 2004									
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	15	209	9.7	21.8	15.8
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	17	146	11	15.2	13.1
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	17	85	11	8.9	10
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	4	94	2.6	9.8	6.2
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	7	71	4.5	7.4	6
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	11	30	7.1	3.1	5.1
Laportea canadensis	WOOD NETTLE	4	-3	Nt P-Forb	4	65	2.6	6.8	4.7
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	9	24	5.8	2.5	4.2
Prunus virginiana	CHOKE CHERRY	2	1	Nt Shrub	5	33	3.2	3.4	3.3
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	6	23	3.9	2.4	3.1
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	6	12	3.9	1.3	2.6
Carex grisea	SEDGE	3	-3	Nt P-Sedge	4	24	2.6	2.5	2.6
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	5	14	3.2	1.5	2.4
Viola striata	CREAM VIOLET	5	-3	Nt P-Forb	3	26	1.9	2.7	2.3
Sambucus canadensis	ELDERBERRY	3	-2	Nt Shrub	6	6	3.9	0.6	2.3
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	5	13	3.2	1.4	2.3
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	3	20	1.9	2.1	2
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb	4	12	2.6	1.3	1.9
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	4	8	2.6	0.8	1.7
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	3	4	1.9	0.4	1.2
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	6	1.3	0.6	1
Symplocarpus foetidus	SKUNK-CABBAGE	6	-5	Nt P-Forb	2	6	1.3	0.6	1

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	1	7	0.6	0.7	0.7
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	1	5	0.6	0.5	0.6
Agrimonia pubescens	SOFT AGRIMONY	5	5	Nt P-Forb	1	3	0.6	0.3	0.5
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	1	3	0.6	0.3	0.5
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	0.6	0.1	0.4
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine	1	1	0.6	0.1	0.4
Sambucus racemosa	RED-BERRIED ELDER	3	2	Nt Shrub	1	1	0.6	0.1	0.4
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	1	2	0.6	0.2	0.4
Fraxinus americana	WHITE ASH	5	3	Nt Tree	1	2	0.6	0.2	0.4
Carex hirtifolia	SEDGE	5	5	Nt P-Sedge	1	1	0.6	0.1	0.4
Acer rubrum	RED MAPLE	1	0	Nt Tree	1	1	0.6	0.1	0.4
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	1	1	0.6	0.1	0.4
Spring 2005									
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	13	187	7.4	20.5	14
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	19	74	10.8	8.1	9.5
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	17	82	9.7	9	9.3
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	3	98	1.7	10.8	6.2
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	7	70	4	7.7	5.8
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	12	26	6.8	2.9	4.8
Laportea canadensis	WOOD NETTLE	4	-3	Nt P-Forb	5	61	2.8	6.7	4.8
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	10	25	5.7	2.7	4.2
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	11	18	6.3	2	4.1
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	6	39	3.4	4.3	3.8
Cryptotaenia canadensis	HONEWORT	2	0	Nt P-Forb	5	29	2.8	3.2	3
Viola striata	CREAM VIOLET	5	-3	Nt P-Forb	4	33	2.3	3.6	2.9
Prunus virginiana	CHOKE CHERRY	2	1	Nt Shrub	6	20	3.4	2.2	2.8
Claytonia virginica	SPRING-BEAUTY	4	3	Nt P-Forb	8	8	4.5	0.9	2.7
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	5	17	2.8	1.9	2.4
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	4	10	2.3	1.1	1.7
Allium tricoccum	WILD LEEK	5	2	Nt P-Forb	4	11	2.3	1.2	1.7
Carex grisea	SEDGE	3	-3	Nt P-Sedge	3	16	1.7	1.8	1.7

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Trillium grandiflorum	COMMON TRILLIUM	5	5	Nt P-Forb	3	8	1.7	0.9	1.3
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	3	9	1.7	1	1.3
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	11	1.1	1.2	1.2
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	9	1.1	1	1.1
Symplocarpus foetidus	SKUNK-CABBAGE	6	-5	Nt P-Forb	2	7	1.1	0.8	1
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	2	7	1.1	0.8	1
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	3	3	1.7	0.3	1
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	2	6	1.1	0.7	0.9
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	2	2	1.1	0.2	0.7
Festuca subverticillata	NODDING FESCUE	5	2	Nt P-Grass	2	2	1.1	0.2	0.7
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	1	4	0.6	0.4	0.5
Carex hirtifolia	SEDGE	5	5	Nt P-Sedge	1	4	0.6	0.4	0.5
Morus rubra	RED MULBERRY	9	1	Nt Tree	1	2	0.6	0.2	0.4
HESPERIS MATRONALIS	DAME'S ROCKET	*	5	Ad P-Forb	1	3	0.6	0.3	0.4
Allium canadense	WILD GARLIC	4	3	Nt P-Forb	1	2	0.6	0.2	0.4
Agrimonia pubescens	SOFT AGRIMONY	5	5	Nt P-Forb	1	2	0.6	0.2	0.4
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	1	2	0.6	0.2	0.4
Smilax tamnoides	BRISTLY GREEN-BRIER	5	0	Nt W-Vine	1	1	0.6	0.1	0.3
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	0.6	0.1	0.3
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	1	1	0.6	0.1	0.3
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	1	1	0.6	0.1	0.3
LUX ARBOR									
Fall 2003									
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	11	31	32.4	14.7	23.5
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	4	55	11.8	26.1	18.9
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	7	28	20.6	13.3	16.9
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	5	19	14.7	9	11.9
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	1	30	2.9	14.2	8.6
RUMEX OBTUSIFOLIUS	BITTER DOCK	*	-3	Ad P-Forb	1	25	2.9	11.8	7.4
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	2	13	5.9	6.2	6

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	1	5	2.9	2.4	2.7
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	1	3	2.9	1.4	2.2
Quercus velutina	BLACK OAK	6	5	Nt Tree	1	2	2.9	0.9	1.9
Fall 2004									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	16	378	32	72.7	52.3
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	7	11	14	2.1	8.1
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	5	19	10	3.7	6.8
Phytolacca americana	POKEWEED	2	1	Nt P-Forb	3	40	6	7.7	6.8
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	3	27	6	5.2	5.6
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	4	10	8	1.9	5
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	3	11	6	2.1	4.1
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	3	9	6	1.7	3.9
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	2	2	4	0.4	2.2
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb	1	6	2	1.2	1.6
Quercus velutina	BLACK OAK	6	5	Nt Tree	1	3	2	0.6	1.3
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	1	2	2	0.4	1.2
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	1	2	2	0.4	1.2
Fall 2005									
Phytolacca americana	POKEWEED	2	1	Nt P-Forb	8	230	9.2	41.5	25.4
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	15	69	17.2	12.5	14.8
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	13	58	14.9	10.5	12.7
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	5	87	5.7	15.7	10.7
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	5	19	5.7	3.4	4.6
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	5	10	5.7	1.8	3.8
Erechtites hieracifolia	FIREWEED	2	3	Nt A-Forb	3	20	3.4	3.6	3.5
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	4	7	4.6	1.3	2.9
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	4	7	4.6	1.3	2.9
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	3	10	3.4	1.8	2.6
TARAXACUM OFFICINALE	COMMON DANDELION	*	3	Ad P-Forb	2	5	2.3	0.9	1.6

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	5	2.3	0.9	1.6
Geranium robertianum	HERB ROBERT	3	5	Nt A-Forb	2	3	2.3	0.5	1.4
Carex cephalophora	SEDGE	3	3	Nt P-Sedge	2	2	2.3	0.4	1.3
TRIFOLIUM REPENS	WHITE CLOVER	*	2	Ad P-Forb	2	2	2.3	0.4	1.3
LEONURUS CARDIACA	MOTHERWORT	*	5	Ad P-Forb	1	6	1.1	1.1	1.1
Quercus velutina	BLACK OAK	6	5	Nt Tree	1	2	1.1	0.4	0.8
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	1	3	1.1	0.5	0.8
Urtica dioica	NETTLE	1	-1	Nt P-Forb	1	1	1.1	0.2	0.7
Acer rubrum	RED MAPLE	1	0	Nt Tree	1	1	1.1	0.2	0.7
CHENOPODIUM ALBUM	LAMB'S QUARTERS	*	1	Ad A-Forb	1	1	1.1	0.2	0.7
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb	1	1	1.1	0.2	0.7
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb	1	1	1.1	0.2	0.7
Juncus tenuis	PATH RUSH	1	0	Nt P-Forb	1	1	1.1	0.2	0.7
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	1	1	1.1	0.2	0.7
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	1.1	0.2	0.7
Solidago caesia	BLUE-STEMMED GOLDENROD	7	3	Nt P-Forb	1	1	1.1	0.2	0.7
Spring 2003									
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	14	141	22.6	28.8	25.7
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	9	156	14.5	31.8	23.2
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	8	19	12.9	3.9	8.4
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	4	48	6.5	9.8	8.1
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	5	39	8.1	8	8
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	4	33	6.5	6.7	6.6
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	3	18	4.8	3.7	4.3
Quercus velutina	BLACK OAK	6	5	Nt Tree	3	6	4.8	1.2	3
Senecio aureus	GOLDEN RAGWORT	5	-3	Nt P-Forb	2	6	3.2	1.2	2.2
Phytolacca americana	POKEWEED	2	1	Nt P-Forb	2	4	3.2	0.8	2
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	5	1.6	1	1.3

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb	1	5	1.6	1	1.3
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	1	4	1.6	0.8	1.2
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	1	2	1.6	0.4	1
Actaea pachypoda	DOLL'S-EYES	7	5	Nt P-Forb	1	1	1.6	0.2	0.9
Oxalis stricta	COMMON YELLOW WOOD-SORREL	0	3	Nt P-Forb	1	1	1.6	0.2	0.9
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	1	1	1.6	0.2	0.9
TRIFOLIUM REPENS	WHITE CLOVER	*	2	Ad P-Forb	1	1	1.6	0.2	0.9
Spring 2004									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	16	346	23.2	46.1	34.6
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	14	136	20.3	18.1	19.2
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	5	108	7.2	14.4	10.8
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	4	37	5.8	4.9	5.4
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	5	23	7.2	3.1	5.2
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	5	20	7.2	2.7	5
Phytolacca americana	POKEWEED	2	1	Nt P-Forb	3	20	4.3	2.7	3.5
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	3	17	4.3	2.3	3.3
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	2	8	2.9	1.1	2
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	9	2.9	1.2	2
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb	2	4	2.9	0.5	1.7
Acer rubrum	RED MAPLE	1	0	Nt Tree	2	2	2.9	0.3	1.6
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb	1	8	1.4	1.1	1.3
Quercus velutina	BLACK OAK	6	5	Nt Tree	1	4	1.4	0.5	1
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	1	4	1.4	0.5	1
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	1	2	1.4	0.3	0.9
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	1	2	1.4	0.3	0.9
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	1	1	1.4	0.1	0.8
Spring 2005									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	15	134	16	23.4	19.7
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	16	104	17	18.2	17.6

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	8	107	8.5	18.7	13.6
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	5	56	5.3	9.8	7.6
Phytolacca americana	POKEWEED	2	1	Nt P-Forb	4	57	4.3	10	7.1
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	6	30	6.4	5.2	5.8
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	6	27	6.4	4.7	5.6
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	6	17	6.4	3	4.7
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	3	7	3.2	1.2	2.2
Erechtites hieracifolia	FIREWEED	2	3	Nt A-Forb	3	3	3.2	0.5	1.9
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	3	3	3.2	0.5	1.9
TRIFOLIUM REPENS	WHITE CLOVER	*	2	Ad P-Forb	3	3	3.2	0.5	1.9
Geranium robertianum	HERB ROBERT	3	5	Nt A-Forb	2	4	2.1	0.7	1.4
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	2	3	2.1	0.5	1.3
Quercus velutina	BLACK OAK	6	5	Nt Tree	2	3	2.1	0.5	1.3
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb	2	2	2.1	0.3	1.2
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	1	3	1.1	0.5	0.8
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	1	3	1.1	0.5	0.8
Acer rubrum	RED MAPLE	1	0	Nt Tree	1	1	1.1	0.2	0.6
ERUCA VESICARIA	ROCKET SALAD; GARDEN ROCKET	*	5	Ad A-Forb	1	1	1.1	0.2	0.6
Galium triflorum	FRAGRANT BEDSTRAW	4	2	Nt P-Forb	1	1	1.1	0.2	0.6
LEONURUS CARDIACA	MOTHERWORT	*	5	Ad P-Forb	1	1	1.1	0.2	0.6
TARAXACUM OFFICINALE	COMMON DANDELION	*	3	Ad P-Forb	1	1	1.1	0.2	0.6
Thalictrum dasycarpum	PURPLE MEADOW-RUE	3	-2	Nt P-Forb	1	1	1.1	0.2	0.6
PINCKNEY									
Fall 2003									
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	12	77	16.9	19.7	18.3
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	10	68	14.1	17.4	15.7
Fraxinus americana	WHITE ASH	5	3	Nt Tree	7	78	9.9	19.9	14.9
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	7	17	9.9	4.3	7.1
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb	6	22	8.5	5.6	7

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Carex pensylvanica	SEDGE	4	5	Nt P-Sedge	3	21	4.2	5.4	4.8
Rubus flagellaris	NORTHERN DEWBERRY	1	4	Nt Shrub	3	20	4.2	5.1	4.7
Viola pubescens	YELLOW VIOLET	4	4	Nt P-Forb	3	18	4.2	4.6	4.4
Thalictrum dioicum	EARLY MEADOW-RUE	6	2	Nt P-Forb	3	9	4.2	2.3	3.3
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	3	8	4.2	2	3.1
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	2	13	2.8	3.3	3.1
Potentilla simplex	OLD-FIELD CINQUEFOIL	2	4	Nt P-Forb	3	5	4.2	1.3	2.8
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	1	15	1.4	3.8	2.6
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	1	10	1.4	2.6	2
Galium concinnum	SHINING BEDSTRAW	5	3	Nt P-Forb	2	4	2.8	1	1.9
Quercus alba	WHITE OAK	5	3	Nt Tree	2	3	2.8	0.8	1.8
Carex rosea	CURLY-STYLED WOOD SEDGE	2	5	Nt P-Sedge	1	1	1.4	0.3	0.8
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	1	1	1.4	0.3	0.8
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	1	1	1.4	0.3	0.8
Fall 2004									
Carex pensylvanica	SEDGE	4	5	Nt P-Sedge	4	69	6	28	17
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	14	19	20.9	7.7	14.3
Fraxinus americana	WHITE ASH	5	3	Nt Tree	6	34	9	13.8	11.4
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree	3	26	4.5	10.6	7.5
Rubus flagellaris	NORTHERN DEWBERRY	1	4	Nt Shrub	3	24	4.5	9.8	7.1
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	5	8	7.5	3.3	5.4
Desmodium glutinosum	CLUSTERED-LEAVED TICK-TREEFOIL	5	5	Nt P-Forb	4	12	6	4.9	5.4
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	3	13	4.5	5.3	4.9
Galium concinnum	SHINING BEDSTRAW	5	3	Nt P-Forb	4	4	6	1.6	3.8
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	2	5	3	2	2.5
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	5	3	2	2.5
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	2	5	3	2	2.5
Dioscorea villosa	WILD YAM	4	1	Nt P-Forb	2	2	3	0.8	1.9
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	2	2	3	0.8	1.9

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Viburnum opulus var. americanum	HIGHBUSH CRANBERRY	5	-3	Nt Shrub	1	4	1.5	1.6	1.6
Carex rosea	CURLY-STYLED WOOD SEDGE	2	5	Nt P-Sedge	1	3	1.5	1.2	1.4
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	1	2	1.5	0.8	1.2
Sassafras albidum	SASSAFRAS	5	3	Nt Tree	1	2	1.5	0.8	1.2
Thalictrum dioicum	EARLY MEADOW-RUE	6	2	Nt P-Forb	1	1	1.5	0.4	0.9
Potentilla simplex	OLD-FIELD CINQUEFOIL	2	4	Nt P-Forb	1	1	1.5	0.4	0.9
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	1	1	1.5	0.4	0.9
Quercus alba	WHITE OAK	5	3	Nt Tree	1	1	1.5	0.4	0.9
Vitis aestivalis	SUMMER GRAPE	6	3	Nt W-Vine	1	1	1.5	0.4	0.9
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	1	1	1.5	0.4	0.9
Prunus virginiana	CHOKE CHERRY	2	1	Nt Shrub	1	1	1.5	0.4	0.9
Fall 2005									
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	5	40	6.3	16.7	11.5
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	13	14	16.3	5.9	11.1
Fraxinus americana	WHITE ASH	5	3	Nt Tree	5	29	6.3	12.1	9.2
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree	4	31	5	13	9
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	8	13	10	5.4	7.7
Carex pensylvanica	SEDGE	4	5	Nt P-Sedge	5	21	6.3	8.8	7.5
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	4	18	5	7.5	6.3
Desmodium glutinosum	CLUSTERED-LEAVED TICK-TREEFOIL	5	5	Nt P-Forb	5	13	6.3	5.4	5.8
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	6	10	7.5	4.2	5.8
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	3	5	3.8	2.1	2.9
Quercus rubra	RED OAK	5	3	Nt Tree	1	10	1.3	4.2	2.7
Rubus flagellaris	NORTHERN DEWBERRY	1	4	Nt Shrub	2	6	2.5	2.5	2.5
Prunus virginiana	CHOKE CHERRY	2	1	Nt Shrub	3	3	3.8	1.3	2.5
Galium concinnum	SHINING BEDSTRAW	5	3	Nt P-Forb	2	5	2.5	2.1	2.3
Viburnum opulus var. americanum	HIGHBUSH CRANBERRY	5	-3	Nt Shrub	1	5	1.3	2.1	1.7
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	2	2	2.5	0.8	1.7
Quercus alba	WHITE OAK	5	3	Nt Tree	2	2	2.5	0.8	1.7

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	2	2.5	0.8	1.7
Potentilla simplex	OLD-FIELD CINQUEFOIL	2	4	Nt P-Forb	1	3	1.3	1.3	1.3
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	1	2	1.3	0.8	1
Uvularia grandiflora	BELLWORT	5	5	Nt P-Forb	1	1	1.3	0.4	0.8
Carex rosea	CURLY-STYLED WOOD SEDGE	2	5	Nt P-Sedge	1	1	1.3	0.4	0.8
Amelanchier arborea	JUNEBERRY	4	3	Nt Tree	1	1	1.3	0.4	0.8
Acer rubrum	RED MAPLE	1	0	Nt Tree	1	1	1.3	0.4	0.8
Acer negundo	BOX ELDER	0	-2	Nt Tree	1	1	1.3	0.4	0.8
Spring 2003									
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb	18	221	18.2	24.5	21.3
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	10	129	10.1	14.3	12.2
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	7	105	7.1	11.6	9.3
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	10	72	10.1	8	9
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	6	72	6.1	8	7
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	7	59	7.1	6.5	6.8
Fraxinus americana	WHITE ASH	5	3	Nt Tree	6	67	6.1	7.4	6.7
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	10	27	10.1	3	6.5
Rubus flagellaris	NORTHERN DEWBERRY	1	4	Nt Shrub	2	60	2	6.6	4.3
Carex pensylvanica	SEDGE	4	5	Nt P-Sedge	6	14	6.1	1.6	3.8
Thalictrum dioicum	EARLY MEADOW-RUE	6	2	Nt P-Forb	4	22	4	2.4	3.2
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	2	37	2	4.1	3.1
Potentilla simplex	OLD-FIELD CINQUEFOIL	2	4	Nt P-Forb	3	3	3	0.3	1.7
Acer rubrum	RED MAPLE	1	0	Nt Tree	2	2	2	0.2	1.1
Galium concinnum	SHINING BEDSTRAW	5	3	Nt P-Forb	2	2	2	0.2	1.1
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	1	5	1	0.6	0.8
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	1	3	1	0.3	0.7
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	1	2	1	0.2	0.6
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	1	1	1	0.1	0.6
Spring 2004									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	16	219	12.9	19.2	16.1

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb	15	157	12.1	13.8	12.9
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	10	158	8.1	13.9	11
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	11	68	8.9	6	7.4
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	7	94	5.6	8.3	6.9
Fraxinus americana	WHITE ASH	5	3	Nt Tree	6	58	4.8	5.1	5
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	10	17	8.1	1.5	4.8
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	6	53	4.8	4.7	4.7
Rubus flagellaris	NORTHERN DEWBERRY	1	4	Nt Shrub	4	38	3.2	3.3	3.3
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree	3	37	2.4	3.2	2.8
Thalictrum dioicum	EARLY MEADOW-RUE	6	2	Nt P-Forb	4	24	3.2	2.1	2.7
Carex pensylvanica	SEDGE	4	5	Nt P-Sedge	4	23	3.2	2	2.6
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	3	25	2.4	2.2	2.3
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	3	18	2.4	1.6	2
Desmodium glutinosum	CLUSTERED-LEAVED TICK-TREEFOIL	5	5	Nt P-Forb	2	24	1.6	2.1	1.9
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	3	13	2.4	1.1	1.8
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	19	1.6	1.7	1.6
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	1	25	0.8	2.2	1.5
Galium concinnum	SHINING BEDSTRAW	5	3	Nt P-Forb	2	14	1.6	1.2	1.4
Potentilla simplex	OLD-FIELD CINQUEFOIL	2	4	Nt P-Forb	2	7	1.6	0.6	1.1
Viburnum opulus var. americanum	HIGHBUSH CRANBERRY	5	-3	Nt Shrub	1	12	0.8	1.1	0.9
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	1	9	0.8	0.8	0.8
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	1	6	0.8	0.5	0.7
Trillium grandiflorum	COMMON TRILLIUM	5	5	Nt P-Forb	1	7	0.8	0.6	0.7
Vitis aestivalis	SUMMER GRAPE	6	3	Nt W-Vine	1	6	0.8	0.5	0.7
Sassafras albidum	SASSAFRAS	5	3	Nt Tree	1	2	0.8	0.2	0.5
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	1	2	0.8	0.2	0.5
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	1	2	0.8	0.2	0.5
Quercus alba	WHITE OAK	5	3	Nt Tree	1	1	0.8	0.1	0.4
Carex rosea	CURLY-STYLED WOOD SEDGE	2	5	Nt P-Sedge	1	1	0.8	0.1	0.4

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	C	W	PHYS	FRQ	COV	RFRQ	RCOV	RIV
Spring 2005									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	20	113	13.9	15.7	14.8
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb	15	104	10.4	14.4	12.4
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	10	101	6.9	14	10.5
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	13	86	9	11.9	10.5
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	15	16	10.4	2.2	6.3
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	11	31	7.6	4.3	6
Fraxinus americana	WHITE ASH	5	3	Nt Tree	5	46	3.5	6.4	4.9
Rubus flagellaris	NORTHERN DEWBERRY	1	4	Nt Shrub	5	26	3.5	3.6	3.5
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	6	16	4.2	2.2	3.2
Podophyllum peltatum	MAY APPLE	3	3	Nt P-Forb	2	35	1.4	4.9	3.1
Carya ovata	SHAGBARK HICKORY	5	3	Nt Tree	3	25	2.1	3.5	2.8
Desmodium glutinosum	CLUSTERED-LEAVED TICK-TREEFOIL	5	5	Nt P-Forb	5	14	3.5	1.9	2.7
Carex pensylvanica	SEDGE	4	5	Nt P-Sedge	5	12	3.5	1.7	2.6
Thalictrum dioicum	EARLY MEADOW-RUE	6	2	Nt P-Forb	4	16	2.8	2.2	2.5
Cornus foemina	GRAY DOGWOOD	1	-2	Nt Shrub	3	10	2.1	1.4	1.7
Prunus virginiana	CHOKE CHERRY	2	1	Nt Shrub	3	5	2.1	0.7	1.4
Carex rosea	CURLY-STYLED WOOD SEDGE	2	5	Nt P-Sedge	2	8	1.4	1.1	1.3
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	2	7	1.4	1	1.2
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	2	3	1.4	0.4	0.9
Trillium grandiflorum	COMMON TRILLIUM	5	5	Nt P-Forb	1	6	0.7	0.8	0.8
Viburnum opulus var. americanum	HIGHBUSH CRANBERRY	5	-3	Nt Shrub	1	7	0.7	1	0.8
Sassafras albidum	SASSAFRAS	5	3	Nt Tree	1	7	0.7	1	0.8
Galium concinnum	SHINING BEDSTRAW	5	3	Nt P-Forb	1	5	0.7	0.7	0.7
Potentilla simplex	OLD-FIELD CINQUEFOIL	2	4	Nt P-Forb	1	4	0.7	0.6	0.6
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	1	4	0.7	0.6	0.6
Acer negundo	BOX ELDER	0	-2	Nt Tree	1	4	0.7	0.6	0.6
Dioscorea villosa	WILD YAM	4	1	Nt P-Forb	1	2	0.7	0.3	0.5
Quercus alba	WHITE OAK	5	3	Nt Tree	1	2	0.7	0.3	0.5

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Vitis aestivalis	SUMMER GRAPE	6	3	Nt W-Vine	1	2	0.7	0.3	0.5
Acer rubrum	RED MAPLE	1	0	Nt Tree	1	1	0.7	0.1	0.4
Hepatica americana	ROUND-LOBED HEPATICA	6	5	Nt P-Forb	1	1	0.7	0.1	0.4
Uvularia grandiflora	BELLWORT	5	5	Nt P-Forb	1	1	0.7	0.1	0.4
RUSS FOREST									
Fall 2003									
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	16	260	35.6	75.1	55.4
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	4	28	8.9	8.1	8.5
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	3	8	6.7	2.3	4.5
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	3	5	6.7	1.4	4.1
Euonymus obovata	RUNNING STRAWBERRY	5	5	Nt Shrub	2	12	4.4	3.5	4
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	3	4	6.7	1.2	3.9
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	2	7	4.4	2	3.2
Quercus alba	WHITE OAK	5	3	Nt Tree	2	6	4.4	1.7	3.1
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	2	4	4.4	1.2	2.8
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	3	4.4	0.9	2.7
Viola rostrata	LONG-SPURRED VIOLET	6	3	Nt P-Forb	2	3	4.4	0.9	2.7
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	2	3	4.4	0.9	2.7
Carex jamesii	JAMES' SEDGE	8	5	Nt P-Sedge	1	2	2.2	0.6	1.4
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	1	1	2.2	0.3	1.3
Fall 2004									
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	17	131	24.6	36	30.3
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	13	32	18.8	8.8	13.8
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	5	43	7.2	11.8	9.5
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	3	46	4.3	12.6	8.5
Quercus alba	WHITE OAK	5	3	Nt Tree	2	47	2.9	12.9	7.9
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	6	8	8.7	2.2	5.4
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	4	5	5.8	1.4	3.6
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	3	7	4.3	1.9	3.1
Viola rostrata	LONG-SPURRED VIOLET	6	3	Nt P-Forb	2	11	2.9	3	3
Acer rubrum	RED MAPLE	1	0	Nt Tree	3	5	4.3	1.4	2.9

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Carex jamesii	JAMES' SEDGE	8	5	Nt P-Sedge	1	15	1.4	4.1	2.8
Phytolacca americana	POKEWEED	2	1	Nt P-Forb	2	3	2.9	0.8	1.9
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	2	2	2.9	0.5	1.7
Euonymus obovata	RUNNING STRAWBERRY	5	5	Nt Shrub	1	3	1.4	0.8	1.1
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb	1	2	1.4	0.5	1
Viola striata	CREAM VIOLET	5	-3	Nt P-Forb	1	1	1.4	0.3	0.9
Maianthemum canadense	CANADA MAYFLOWER	4	0	Nt P-Forb	1	1	1.4	0.3	0.9
Lindera benzoin	SPICEBUSH	7	-2	Nt Shrub	1	1	1.4	0.3	0.9
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	1	1	1.4	0.3	0.9
Spring 2003									
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	17	455	18.5	53.2	35.8
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	14	54	15.2	6.3	10.8
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	16	18	17.4	2.1	9.7
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	9	78	9.8	9.1	9.4
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	6	104	6.5	12.1	9.3
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	3	57	3.3	6.7	5
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	3	21	3.3	2.5	2.9
Quercus alba	WHITE OAK	5	3	Nt Tree	4	5	4.3	0.6	2.5
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	3	10	3.3	1.2	2.2
Viola rostrata	LONG-SPURRED VIOLET	6	3	Nt P-Forb	3	9	3.3	1.1	2.2
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	2	11	2.2	1.3	1.7
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	4	2.2	0.5	1.3
Carex jamesii	JAMES' SEDGE	8	5	Nt P-Sedge	2	3	2.2	0.4	1.3
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	2	2	2.2	0.2	1.2
Euonymus obovata	RUNNING STRAWBERRY	5	5	Nt Shrub	1	7	1.1	0.8	1
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	1	8	1.1	0.9	1
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	1	5	1.1	0.6	0.8
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	1	3	1.1	0.4	0.7
Dentaria laciniata	CUT-LEAVED TOOTHWORT	5	3	Nt P-Forb	1	1	1.1	0.1	0.6
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	1	1.1	0.1	0.6
Spring 2004									

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	20	299	22	45.3	33.6
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	14	98	15.4	14.8	15.1
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	11	29	12.1	4.4	8.2
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	7	51	7.7	7.7	7.7
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	4	73	4.4	11.1	7.7
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	11	11	12.1	1.7	6.9
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	1	40	1.1	6.1	3.6
Quercus alba	WHITE OAK	5	3	Nt Tree	3	8	3.3	1.2	2.3
Viola rostrata	LONG-SPURRED VIOLET	6	3	Nt P-Forb	3	9	3.3	1.4	2.3
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	3	4	3.3	0.6	2
Acer rubrum	RED MAPLE	1	0	Nt Tree	2	6	2.2	0.9	1.6
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	2	4	2.2	0.6	1.4
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	2	4	2.2	0.6	1.4
Dentaria laciniata	CUT-LEAVED TOOTHWORT	5	3	Nt P-Forb	2	2	2.2	0.3	1.3
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	1	7	1.1	1.1	1.1
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	1	6	1.1	0.9	1
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	1	4	1.1	0.6	0.9
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	1	3	1.1	0.5	0.8
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb	1	1	1.1	0.2	0.6
Maianthemum canadense	CANADA MAYFLOWER	4	0	Nt P-Forb	1	1	1.1	0.2	0.6
Spring 2005									
Acer saccharum	SUGAR MAPLE	5	3	Nt Tree	20	332	19.4	48	33.7
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	13	66	12.6	9.6	11.1
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	15	16	14.6	2.3	8.4
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	9	50	8.7	7.2	8
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	4	74	3.9	10.7	7.3
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	2	76	1.9	11	6.5
Osmorhiza claytonii	HAIRY SWEET-CICELY	4	4	Nt P-Forb	8	13	7.8	1.9	4.8
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	5	6	4.9	0.9	2.9
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	4	7	3.9	1	2.4
Carex jamesii	JAMES' SEDGE	8	5	Nt P-Sedge	2	10	1.9	1.4	1.7

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Osmorhiza longistylis	SMOOTH SWEET-CICELY	3	4	Nt P-Forb	3	3	2.9	0.4	1.7
Viola rostrata	LONG-SPURRED VIOLET	6	3	Nt P-Forb	2	8	1.9	1.2	1.5
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	2	7	1.9	1	1.5
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	2	5	1.9	0.7	1.3
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	2	3	1.9	0.4	1.2
Impatiens capensis	SPOTTED TOUCH-ME-NOT	2	-3	Nt A-Forb	2	2	1.9	0.3	1.1
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	1	3	1	0.4	0.7
Quercus alba	WHITE OAK	5	3	Nt Tree	1	2	1	0.3	0.6
Claytonia virginica	SPRING-BEAUTY	4	3	Nt P-Forb	1	1	1	0.1	0.6
Dentaria laciniata	CUT-LEAVED TOOTHWORT	5	3	Nt P-Forb	1	1	1	0.1	0.6
Desmodium nudiflorum	NAKED TICK-TREFOIL	7	5	Nt P-Forb	1	2	1	0.3	0.6
Dicentra canadensis	SQUIRREL CORN	7	5	Nt P-Forb	1	1	1	0.1	0.6
Euonymus obovata	RUNNING STRAWBERRY	5	5	Nt Shrub	1	1	1	0.1	0.6
Maianthemum canadense	CANADA MAYFLOWER	4	0	Nt P-Forb	1	2	1	0.3	0.6
SHIAWASSEE									
Fall 2003									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	17	376	17	23.6	20.3
LYSIMACHIA NUMMULARIA	MONEYWORT	*	-4	Ad P-Forb	10	447	10	28	19
Solidago gigantea	LATE GOLDENROD	3	-3	Nt P-Forb	12	260	12	16.3	14.1
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	8	165	8	10.3	9.2
Ribes americanum	WILD BLACK CURRANT	6	-3	Nt Shrub	9	106	9	6.6	7.8
Thalictrum dasycarpum	PURPLE MEADOW-RUE	3	-2	Nt P-Forb	10	66	10	4.1	7.1
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	5	44	5	2.8	3.9
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	4	32	4	2	3
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	4	6	4	0.4	2.2
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	3	14	3	0.9	1.9
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	2	15	2	0.9	1.5
Eupatorium rugosum	WHITE SNAKEROOT	4	3	Nt P-Forb	1	30	1	1.9	1.4
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	2	6	2	0.4	1.2
Carex grayi	SEDGE	6	-4	Nt P-Sedge	2	2	2	0.1	1.1

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	7	1	0.4	0.7
Urtica dioica	NETTLE	1	-1	Nt P-Forb	1	5	1	0.3	0.7
Polygonatum biflorum	SOLOMON-SEAL	4	3	Nt P-Forb	1	5	1	0.3	0.7
Ranunculus hispidus	SWAMP BUTTERCUP	5	0	Nt P-Forb	1	2	1	0.1	0.6
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	1	2	1	0.1	0.6
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	1	0.1	0.5
Aster ontarionis	ONTARIO ASTER	6	0	Nt P-Forb	1	1	1	0.1	0.5
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	1	1	1	0.1	0.5
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	1	1	1	0.1	0.5
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	1	1	1	0.1	0.5
Crataegus punctata	DOTTED HAWTHORN	1	5	Nt Tree	1	1	1	0.1	0.5
Fall 2004									
LYSIMACHIA NUMMULARIA	MONEYWORT	*	-4	Ad P-Forb	11	716	11.2	66.2	38.7
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	14	45	14.3	4.2	9.2
Solidago gigantea	LATE GOLDENROD	3	-3	Nt P-Forb	11	63	11.2	5.8	8.5
Thalictrum dasycarpum	PURPLE MEADOW-RUE	3	-2	Nt P-Forb	13	22	13.3	2	7.6
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	5	77	5.1	7.1	6.1
Lysimachia ciliata	FRINGED LOOSESTRIFE	4	-3	Nt P-Forb	6	22	6.1	2	4.1
Ribes americanum	WILD BLACK CURRANT	6	-3	Nt Shrub	6	17	6.1	1.6	3.8
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	4	11	4.1	1	2.5
Teucrium canadense	WOOD SAGE	4	-2	Nt P-Forb	2	28	2	2.6	2.3
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	2	19	2	1.8	1.9
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	3	4	3.1	0.4	1.7
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	2	11	2	1	1.5
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	2	5	2	0.5	1.3
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	3	2	0.3	1.2
Carex grayi	SEDGE	6	-4	Nt P-Sedge	2	2	2	0.2	1.1
Ranunculus recurvatus	HOOKED CROWFOOT	5	-3	Nt A-Forb	1	12	1	1.1	1.1
Sambucus canadensis	ELDERBERRY	3	-2	Nt Shrub	1	6	1	0.6	0.8
Aster ontarionis	ONTARIO ASTER	6	0	Nt P-Forb	1	3	1	0.3	0.6

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	3	1	0.3	0.6
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	1	2	1	0.2	0.6
Quercus velutina	BLACK OAK	6	5	Nt Tree	1	1	1	0.1	0.6
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	1	0.1	0.6
Lobelia siphilitica	GREAT BLUE LOBELIA	4	-4	Nt P-Forb	1	2	1	0.2	0.6
Juglans nigra	BLACK WALNUT	5	3	Nt Tree	1	1	1	0.1	0.6
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	1	0.1	0.6
Aster lanceolatus	EASTERN LINED ASTER	2	-3	Nt P-Forb	1	3	1	0.3	0.6
Acer saccharinum	SILVER MAPLE	2	-3	Nt Tree	1	1	1	0.1	0.6
Erigeron philadelphicus	MARSH FLEABANE	2	-3	Nt P-Forb	1	1	1	0.1	0.6
Fall 2005									
LYSIMACHIA NUMMULARIA	MONEYWORT	*	-4	Ad P-Forb	11	811	8.7	55.9	32.3
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	17	188	13.4	13	13.2
Solidago gigantea	LATE GOLDENROD	3	-3	Nt P-Forb	12	89	9.4	6.1	7.8
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	13	42	10.2	2.9	6.6
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	11	59	8.7	4.1	6.4
Thalictrum dasycarpum	PURPLE MEADOW-RUE	3	-2	Nt P-Forb	12	22	9.4	1.5	5.5
Ribes americanum	WILD BLACK CURRANT	6	-3	Nt Shrub	9	34	7.1	2.3	4.7
Teucrium canadense	WOOD SAGE	4	-2	Nt P-Forb	2	102	1.6	7	4.3
Lysimachia ciliata	FRINGED LOOSESTRIFE	4	-3	Nt P-Forb	6	10	4.7	0.7	2.7
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	3	31	2.4	2.1	2.2
Aster ontarionis	ONTARIO ASTER	6	0	Nt P-Forb	4	12	3.1	0.8	2
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	4	11	3.1	0.8	2
Carex grayi	SEDGE	6	-4	Nt P-Sedge	4	4	3.1	0.3	1.7
Ranunculus recurvatus	HOOKED CROWFOOT	5	-3	Nt A-Forb	3	6	2.4	0.4	1.4
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	3	3	2.4	0.2	1.3
Lobelia siphilitica	GREAT BLUE LOBELIA	4	-4	Nt P-Forb	1	5	0.8	0.3	0.6
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	1	3	0.8	0.2	0.5
Boehmeria cylindrica	FALSE NETTLE	5	-5	Nt P-Forb	1	2	0.8	0.1	0.5
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	1	2	0.8	0.1	0.5

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	1	2	0.8	0.1	0.5
Ulmus americana	AMERICAN ELM	1	-2	Nt Tree	1	2	0.8	0.1	0.5
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	4	0.8	0.3	0.5
Geranium maculatum	WILD GERANIUM	4	3	Nt P-Forb	1	2	0.8	0.1	0.5
Acer negundo	BOX ELDER	0	-2	Nt Tree	1	1	0.8	0.1	0.4
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	0.8	0.1	0.4
Celtis occidentalis	HACKBERRY	5	1	Nt Tree	1	1	0.8	0.1	0.4
Elymus virginicus	VIRGINIA WILD-RYE	4	-2	Nt P-Grass	1	1	0.8	0.1	0.4
Pilea pumila	CLEARWEED	5	-3	Nt A-Forb	1	1	0.8	0.1	0.4
Spring 2003									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	14	720	9.3	37	23.1
LYSIMACHIA NUMMULARIA	MONEYWORT	*	-4	Ad P-Forb	10	374	6.6	19.2	12.9
Solidago gigantea	LATE GOLDENROD	3	-3	Nt P-Forb	13	190	8.6	9.8	9.2
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	11	186	7.3	9.6	8.4
Thalictrum dasycarpum	PURPLE MEADOW-RUE	3	-2	Nt P-Forb	14	141	9.3	7.2	8.3
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	12	65	7.9	3.3	5.6
Ribes americanum	WILD BLACK CURRANT	6	-3	Nt Shrub	9	85	6	4.4	5.2
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	8	26	5.3	1.3	3.3
Allium canadense	WILD GARLIC	4	3	Nt P-Forb	7	7	4.6	0.4	2.5
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	5	15	3.3	0.8	2
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	5	7	3.3	0.4	1.8
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	5	5	3.3	0.3	1.8
Arisaema dracontium	GREEN DRAGON	8	-3	Nt P-Forb	4	9	2.6	0.5	1.6
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	3	20	2	1	1.5
Acer negundo	BOX ELDER	0	-2	Nt Tree	4	5	2.6	0.3	1.5
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	3	7	2	0.4	1.2
Carex grayi	SEDGE	6	-4	Nt P-Sedge	3	7	2	0.4	1.2
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	3	7	2	0.4	1.2
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	2	15	1.3	0.8	1

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	5	1.3	0.3	0.8
Anemone canadensis	CANADA ANEMONE	4	-3	Nt P-Forb	2	4	1.3	0.2	0.8
Laportea canadensis	WOOD NETTLE	4	-3	Nt P-Forb	1	15	0.7	0.8	0.7
Eupatorium rugosum	WHITE SNAKEROOT	4	3	Nt P-Forb	1	10	0.7	0.5	0.6
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	10	0.7	0.5	0.6
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	0.7	0.1	0.4
TARAXACUM OFFICINALE	COMMON DANDELION	*	3	Ad P-Forb	1	1	0.7	0.1	0.4
Sanicula gregaria	BLACK SNAKEROOT	2	-1	Nt P-Forb	1	2	0.7	0.1	0.4
Ranunculus hispidus	SWAMP BUTTERCUP	5	0	Nt P-Forb	1	1	0.7	0.1	0.4
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	1	1	0.7	0.1	0.4
Impatiens capensis	SPOTTED TOUCH-ME-NOT	2	-3	Nt A-Forb	1	1	0.7	0.1	0.4
BRASSICA NIGRA	BLACK MUSTARD	*	5	Ad A-Forb	1	3	0.7	0.2	0.4
Carex grisea	SEDGE	3	-3	Nt P-Sedge	1	1	0.7	0.1	0.4
Elymus villosus	SILKY WILD-RYE	5	3	Nt P-Grass	1	1	0.7	0.1	0.4
Spring 2004									
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	15	622	10.9	34.4	22.7
LYSIMACHIA NUMMULARIA	MONEYWORT	*	-4	Ad P-Forb	11	398	8	22	15
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	10	208	7.3	11.5	9.4
Solidago gigantea	LATE GOLDENROD	3	-3	Nt P-Forb	13	142	9.5	7.8	8.7
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	14	66	10.2	3.6	6.9
Thalictrum dasycarpum	PURPLE MEADOW-RUE	3	-2	Nt P-Forb	13	64	9.5	3.5	6.5
Ribes americanum	WILD BLACK CURRANT	6	-3	Nt Shrub	9	50	6.6	2.8	4.7
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	8	40	5.8	2.2	4
Smilacina racemosa	FALSE SPIKENARD	5	3	Nt P-Forb	7	15	5.1	0.8	3
Acer negundo	BOX ELDER	0	-2	Nt Tree	2	70	1.5	3.9	2.7
Arisaema dracontium	GREEN DRAGON	8	-3	Nt P-Forb	5	11	3.6	0.6	2.1
Allium canadense	WILD GARLIC	4	3	Nt P-Forb	4	5	2.9	0.3	1.6
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	2	23	1.5	1.3	1.4
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	3	10	2.2	0.6	1.4
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	2	20	1.5	1.1	1.3

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Teucrium canadense	WOOD SAGE	4	-2	Nt P-Forb	2	16	1.5	0.9	1.2
Dioscorea villosa	WILD YAM	4	1	Nt P-Forb	2	8	1.5	0.4	1
Lysimachia ciliata	FRINGED LOOSESTRIFE	4	-3	Nt P-Forb	2	8	1.5	0.4	1
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	2	2	1.5	0.1	0.8
Urtica dioica	NETTLE	1	-1	Nt P-Forb	1	4	0.7	0.2	0.5
Ranunculus hispidus	SWAMP BUTTERCUP	5	0	Nt P-Forb	1	5	0.7	0.3	0.5
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	5	0.7	0.3	0.5
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	1	4	0.7	0.2	0.5
Ranunculus recurvatus	HOOKED CROWFOOT	5	-3	Nt A-Forb	1	2	0.7	0.1	0.4
Sambucus canadensis	ELDERBERRY	3	-2	Nt Shrub	1	3	0.7	0.2	0.4
Vitis riparia	RIVERBANK GRAPE	3	-2	Nt W-Vine	1	2	0.7	0.1	0.4
Elymus virginicus	VIRGINIA WILD-RYE	4	-2	Nt P-Grass	1	1	0.7	0.1	0.4
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	1	2	0.7	0.1	0.4
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	0.7	0.1	0.4
Aster ontarionis	ONTARIO ASTER	6	0	Nt P-Forb	1	3	0.7	0.2	0.4
Spring 2005									
LYSIMACHIA NUMMULARIA	MONEYWORT	*	-4	Ad P-Forb	12	833	7.6	43.5	25.6
ALLIARIA PETIOLATA	GARLIC MUSTARD	*	0	Ad B-Forb	18	414	11.5	21.6	16.6
Parthenocissus quinquefolia	VIRGINIA CREEPER	5	1	Nt W-Vine	12	138	7.6	7.2	7.4
Solidago gigantea	LATE GOLDENROD	3	-3	Nt P-Forb	13	97	8.3	5.1	6.7
Thalictrum dasycarpum	PURPLE MEADOW-RUE	3	-2	Nt P-Forb	12	76	7.6	4	5.8
Geum canadense	WHITE AVENS	1	0	Nt P-Forb	13	58	8.3	3	5.7
Circaea lutetiana	ENCHANTER'S-NIGHTSHADE	2	3	Nt P-Forb	12	36	7.6	1.9	4.8
Ribes americanum	WILD BLACK CURRANT	6	-3	Nt Shrub	7	57	4.5	3	3.7
Arisaema dracontium	GREEN DRAGON	8	-3	Nt P-Forb	10	16	6.4	0.8	3.6
Allium canadense	WILD GARLIC	4	3	Nt P-Forb	7	9	4.5	0.5	2.5
Polygonatum pubescens	DOWNY SOLOMON SEAL	5	5	Nt P-Forb	6	11	3.8	0.6	2.2
Lysimachia ciliata	FRINGED LOOSESTRIFE	4	-3	Nt P-Forb	5	22	3.2	1.2	2.2
Rubus occidentalis	BLACK RASPBERRY	1	5	Nt Shrub	3	21	1.9	1.1	1.5
Teucrium canadense	WOOD SAGE	4	-2	Nt P-Forb	2	32	1.3	1.7	1.5

Appendix 2. (cont'd)

SCIENTIFIC NAME	COMMON NAME	*C*	*W*	*PHYS*	*FRQ*	*COV*	*RFRQ*	*RCOV*	*RIV*
Toxicodendron radicans	POISON-IVY	2	-1	Nt W-Vine	3	8	1.9	0.4	1.2
LONICERA MAACKII	AMUR HONEYSUCKLE	*	5	Ad Shrub	1	20	0.6	1	0.8
Carex grayi	SEDGE	6	-4	Nt P-Sedge	2	3	1.3	0.2	0.7
Galium aparine	ANNUAL BEDSTRAW	0	3	Nt A-Forb	2	2	1.3	0.1	0.7
Polygonum virginianum	JUMPSEED	4	0	Nt P-Forb	2	4	1.3	0.2	0.7
Ranunculus recurvatus	HOOKED CROWFOOT	5	-3	Nt A-Forb	1	10	0.6	0.5	0.6
Viola cucullata	MARSH VIOLET	5	-5	Nt P-Forb	1	6	0.6	0.3	0.5
Fraxinus pennsylvanica	RED ASH	2	-3	Nt Tree	1	8	0.6	0.4	0.5
Rubus allegheniensis	COMMON BLACKBERRY	1	2	Nt Shrub	1	8	0.6	0.4	0.5
Sambucus canadensis	ELDERBERRY	3	-2	Nt Shrub	1	5	0.6	0.3	0.4
Impatiens capensis	SPOTTED TOUCH-ME-NOT	2	-3	Nt A-Forb	1	3	0.6	0.2	0.4
Juglans nigra	BLACK WALNUT	5	3	Nt Tree	1	3	0.6	0.2	0.4
Ribes cynosbati	PRICKLY or WILD GOOSEBERRY	4	5	Nt Shrub	1	5	0.6	0.3	0.4
Arisaema triphyllum	JACK-IN-THE-PULPIT	5	-2	Nt P-Forb	1	2	0.6	0.1	0.4
ROSA MULTIFLORA	MULTIFLORA ROSE	*	3	Ad Shrub	1	1	0.6	0.1	0.3
Prunus serotina	WILD BLACK CHERRY	2	3	Nt Tree	1	1	0.6	0.1	0.3
Urtica dioica	NETTLE	1	-1	Nt P-Forb	1	1	0.6	0.1	0.3
Elymus virginicus	VIRGINIA WILD-RYE	4	-2	Nt P-Grass	1	1	0.6	0.1	0.3
Dioscorea villosa	WILD YAM	4	1	Nt P-Forb	1	1	0.6	0.1	0.3
Carex blanda	SEDGE	1	0	Nt P-Sedge	1	1	0.6	0.1	0.3