Distribution and Spread of the Invasive Biennial *Alliaria petiolata* (Garlic Mustard) in North America

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INTRODUCTION

Alliaria petiolata (Bieb. [Cavara & Grande]) is a cool-season, shade-tolerant, obligate biennial herb that invades forested natural communities in the Midwestern and northeastern United States and adjacent Canada (Fig. 1). *Alliaria petiolata* is often referred to as *Alliaria officinalis* Andrz; earlier names included *Alliaria alliaria L. (Britton), Sisymbrium alliaria Scop., Sisymbrium officinalis DC* and *Erysimum alliaria L. Alliaria petiolata* (hereafter referred to as *Alliaria*) is commonly known as garlic mustard, in reference to the strong garlic fragrance produced when the plant is crushed. Other common names include hedge garlic, jack-by-the-hedge, and sauce-alone (Georgia 1920). The plant is native to northern Europe, south of 68°N (Tutin et al. 1964), ranging from England to Sweden to the western region of the former USSR, and south to Italy. From this native range, *Alliaria* has spread to North Africa, India, Sri Lanka (Rai et al. 1972 and Fernaldo 1971, *in* Cavers et al. 1979) as well as Canada (Cavers et al. 1979) and the United States (Gray et al. 1889; Fernald 1970). The North American range of *Alliaria* extends from British Columbia (Cavers et al. 1979) to New England (Gleason and Cronquist 1963) and south to Missouri (Yatskievych and Turner 1990). Regional distribution has been mapped for Wisconsin (Patman and Iltis 1961), North Carolina (Radford et al. 1965), Kansas, Minnesota, North Dakota (Barkley 1977), Canada (Cavers et al. 1979), southern New York (Brooks 1983), Michigan (Voss 1985), Illinois (Nuzzo 1991c), and Ohio (Furlow 1991).

Life history and biology of this European mustard have been investigated by Murley (1951), Trimbur (1973), Lhostka (1975), Cavers et al. (1979), Roberts and Boddrell (1983), Byers and Quinn (1987, 1988), Babonjo et al. (1990) and Kelley et al. (1991) and summarized in Cavers et al. (1979), and Nuzzo (1991a). *Alliaria* germinates in early spring, overwinters as a basal rosette, flowers the following spring, and produces seed in summer, some 15 months after germinating. Plants produce an average of 350 seeds, and individual plants may produce up to 7,900 seeds (Nuzzo, unpubl.). Seeds have a variable dormancy period, germinating in 8 months in Kentucky (Baskin and Baskin 1992) and in 20 months in Ontario (Cavers et al. 1979).

Alliaria invades shaded communities, habitat essentially unoccupied by other invasive alien herbs. The plant most frequently invades wet to dry-mesic deciduous forests but also occurs in the partial shade characteristic of oak savannas, forest edges, shaded roadsides, in urban areas, and occasionally in full sun, particularly in areas exposed to periodic disturbance.

Alliaria threatens the floristic structure of invaded natural communities (Schwegman 1989), particularly the herbaceous layer. First recognized as a prob-

1. Native Landscapes, 1947 Madron Dr., Rockford, IL 61107

FIGURE 1.—Garlic mustard in Cook County Forest Preserve District, Illinois. (photo by Bill Glass)

lem species in Ontario (Cavers et al. 1979), this European mustard was not considered a threat in the United States until the late 1980s. In a 1986 survey of 25 natural areas botanists throughout Illinois, which requested a rank-ordered list of the 10 most problematic exotic plants in the state, *Alliaria* was not listed by any of those surveyed (B. N. McKnight pers. comm.). By 1991 many Midwest states had identified *Alliaria* as a species of concern, and methods to control the plant in natural communities were under study (Nuzzo 1991a, 1991b).

DISTRIBUTION AND SPREAD

Entry, spread, and distribution of *Alliaria* were determined using >1,150 collection records obtained from 77 North American herbaria, supplemented by sight observations made between 1989 and 1991 by field biologists, site stewards, and the author. The resulting distribution map (Fig. 2) depicts within 20-year periods the first record or observation of *Alliaria* within 15-minute topographic quadrangles (approximately 590 km^2 in northern Illinois) in the northcentral

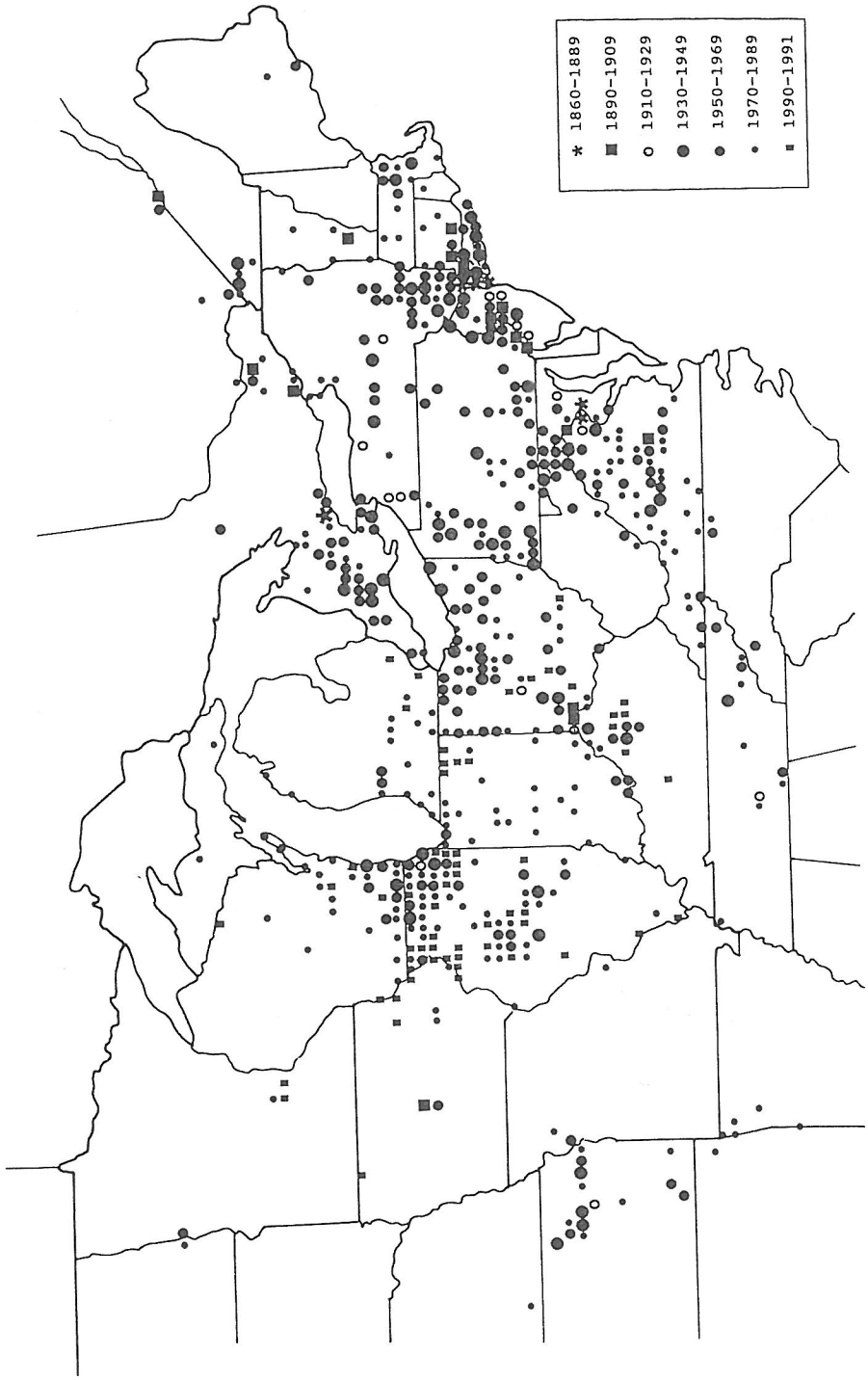

FIGURE 2.—*Alliaria petiolata* distribution in eastern North America 1868–1991, mapped by first record of occurrence within 15′ topographic quadrangles.

U.S. and adjacent Canada. Infrequent collections from western regions were not mapped.

This map is subject to certain limitations. First, distribution maps based on herbarium records represent only the minimum presence of a species and presumably underestimate actual rate of spread and distribution. Second, mapping the first record of an invasive species within equi-sized blocks provides a reliable measure of the rate of invasion through space but not of the extent of invasion within a block (Mack 1985).

Alliaria was first recorded in North America in 1868 on Long Island, New York (Leggett *s.n.* NYS). Spread was initially gradual, with presence reported in just six quadrangles in the next 21 years (Table 1). Multiple collections made within these quadrangles indicate that the species was locally abundant. Lack of collection outside the six quadrangles implies that the species had not spread far from the initial invasion site and/or that collectors worked only within a limited area.

TABLE 1. First record of *Alliaria petiolata* occurrence within 15-minute topographic quadrangles (approximately 590 km²) in the United States and Canada.

	1868–1889	1890–1909	1910–1929	1930–1949	1950–1969	1970–1989	1990–1991	TOTAL
United States	5	16	13	58	158	233	57	540
Canada	1	3	0	8	21	21	0	54
Total	6	19	13	66	179	254	57	594
Cumulative	6	25	38	104	283	537	594	

In the next 20 years (1890–1909) *Alliaria* was collected from an additional 19 locations, including the St. Lawrence Valley in Canada as well as Idaho, Iowa, and Ohio. By 1929, 61 years after the first collection, *Alliaria* had been recorded from a total of 38 quadrangles in 11 states and 2 provinces. The rate of spread, or of collection, increased in the following decades. By 1989 Alliaria was recorded from 537 topographic blocks. An additional 57 blocks were recorded in 1990–1991, all but two based on sight observations. The paucity of herbarium collections since 1989 may reflect the tendency for an invasive species to be well-collected in the early stages of invasion and under-collected in the later stages, once it is established in a locale and considered to be an 'undesirable' or 'weedy' species.

By the end of 1991 *Alliaria* occurred in a minimum of 594 topographic quadrangles in 30 states and 3 provinces. What is not apparent is the extent of infestation within each quadrangle. In Illinois virtually all available habitat in the Chicago region supports *Alliaria,* while southern counties have very localized infestations. Throughout the state 30 percent of state parks and 31 percent of dedicated nature preserves support populations of this species (Nuzzo 1991c).

Graphing the quadrangle occurrences cumulatively by 30-year periods produces a distinct j curve (Fig. 3), reflecting the exponential spread of this plant. *Alliaria* spread gradually during the first 60 years (1868–1929), at a rate of approximately 0.6 quadrangle or 366 km²/year. The rate of spread increased substantially beginning in 1930 (3.3 quadrangles or 1,950 km²/year between 1930 and 1949) and jumped dramatically again after 1950 (8.9 quadrangles or 5,280 km²/year). As of 1991 there was no indication of leveling off. On the basis of the 433 quadrangle occurrences between 1950 and 1989, *Alliaria* is spreading, or being recorded, at the rate of some 10.8 quadrangles or 6,400 km²/year. It must

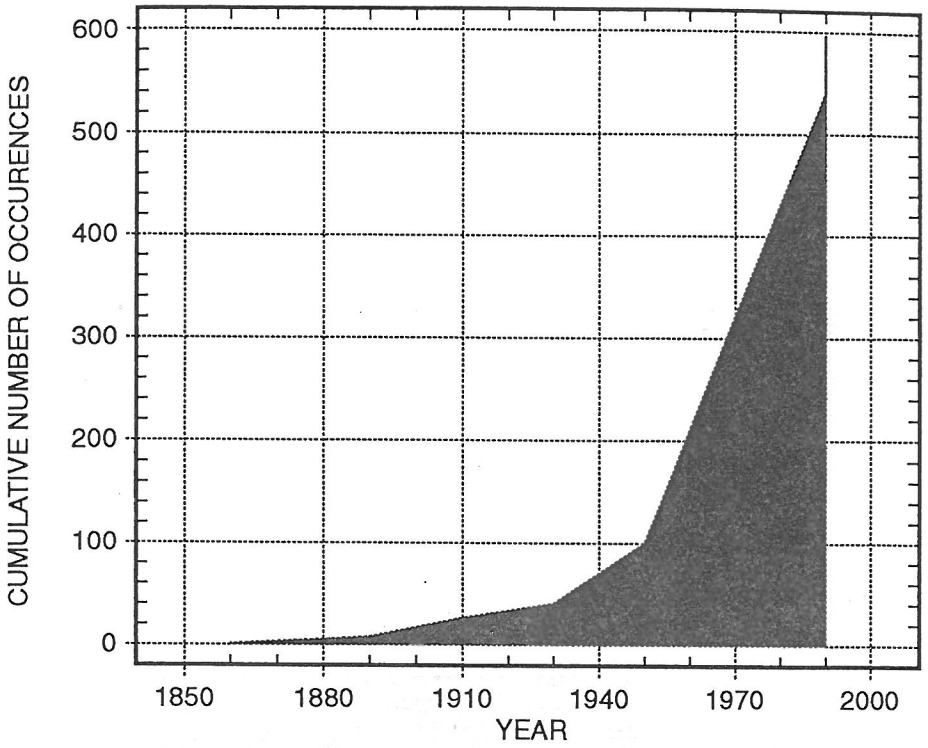

FIGURE 3.—*Alliaria petiolata* presence in North America.

be emphasized that this figure reflects only presence, and not abundance, of plants within each topographic quadrangle.

The rate of spread of *Alliaria* is greater than that recorded for purple loosestrife (*Lythrum salicaria*; 645 km²/year since 1940 [Thompson 1991]) but considerably less than documented for cheat grass (*Bromus tectorum*; all available habitat in 30 years [Mack 1981]). The rapid increase in *Alliaria* spread is consistent with increases recorded for other alien species, beginning approximately 40 to 50 years after initial invasion (Lacey 1957; Thompson et al. 1987).

Spread progressed from the northeastern seaboard westward, a pattern typical of many invasive European species. Regional spread of *Alliaria* has two components; establishment of multiple satellite populations (*sensu* Auld et al. 1978; Auld and Coote 1980) often separated by great distances, and spread as an advancing front from population centers. Eventually the satellite populations coalesce. Both modes are noticeable in Fig. 2, which depicts the minimum presence of *Alliaria* as of 1991. Infrequent collections from western North America imply that the species may be a sporadic rather than established component of the regional flora.

Within individual communities *Alliaria* population size may fluctuate widely from year to year, reflecting both the biennial nature of this plant and the 20-month seed dormancy of northern plants. Across a region *Alliaria* presence consistently increases through time. In seven northern Illinois forests *Alliaria* occurred at an average frequency of 24 percent in 1989, 34 percent in 1990, and 46 percent in 1991 (Nuzzo, unpubl.). *Alliaria* abundance in these same communities, as measured by percent cover, showed a modest but non-significant increase during the same time period. This implies an invasion strategy whereby *Alliaria* initially

spreads relatively rapidly through a site at low density and subsequently establishes higher density populations. On a generational basis *Alliaria*'s presence within a community also consistently increases, by an average of 250 percent (Nuzzo, unpubl.). The increase is considerably greater at sites subjected to disturbance, where presence of *Alliaria* increased more than 14-fold between generations.

Alliaria, like many invasive alien herbs, is disturbance-adapted, and both natural and anthropogenic disturbance factors are associated with the rapid invasion rate in natural communities (Nuzzo 1991c). Naturally disturbed habitats such as floodplains and riverbanks and anthropogenically disturbed habitats such as roadsides, heavily used preserves, and urban areas are the primary dispersal corridors for *Alliaria.* Disturbances create habitat suitable for initial entry, and continued disturbances maintain habitat suitable for expansion. However, once established in a locale, additional disturbance may not be necessary for continued spread of *Alliaria* (*sensu* Mack 1985). Exponential expansion of other weed species has been correlated with various anthropogenic disturbances (Lacey 1957; Mack 1981; Forcella and Harvey 1983; Thompson et al. 1987).

HABITAT

Habitat data were compiled from the 705 U.S. collection records that indicated habitat. *Alliaria* was most frequently collected in forests, along roads, and near rivers; > 75 percent of collections were made near one of these habitats. Eight percent were made in urban areas, 4 percent in arboreta or on campuses, and 3 percent along railroads.

Roads (21%) and rivers (23%) were the primary collection locations indicated on 296 records from northeastern states (Conn., Del., Mass., Md., Maine, N.H., N.J., N.Y., Pa., Vt., and the District of Columbia), followed by forested riverbanks (14%), other forested areas (13%), and urban areas (9%) (Fig. 4). In 146 records from southeastern states (Ky., N.C., Va., and W.Va.) slightly more collections were made on forested riverbanks (21%) than along roads (18%), rivers (16%), or forests (16%). In contrast in the Midwestern states (Iowa, Ill., Ind., Kans., Mich., Minn., Mo., Ohio, and Wis.), 30 percent of the 260 collections were made in forests, 14 percent along roads, and 10 percent along rivers or other wet areas. Interestingly, 5 percent of the Midwestern collections were made along railroads.

Regional differences in collection locations have many causes, and cannot be attributed solely to habitat preference of the collected species. However, the decline in river-associated habitat from Northeast to Southeast to Midwest and concomitant increase in non-riverine forest habitat may indicate that *Alliaria* preferentially invades drier forest communities in the Midwest than in the Northeast. This is supported by the higher presence along railroads, which are generally indicative of drier habitats.

CONTROL

Active management to eliminate *Alliaria* from natural areas and to limit invasion into new locales may slow the spread of this plant. Generally effective methods include removal of the flowerstalk prior to seed production, dormant-season prescribed fire, and dormant-season herbicide application (Nuzzo 1991a, 1991b). Such management is feasible in isolated forested communities and in regions where *Alliaria* has low presence. *Alliaria* is self-compatible (Cavers et al. 1979; Babonjo et al. 1990), and a single plant is sufficient to populate or repopulate a site.

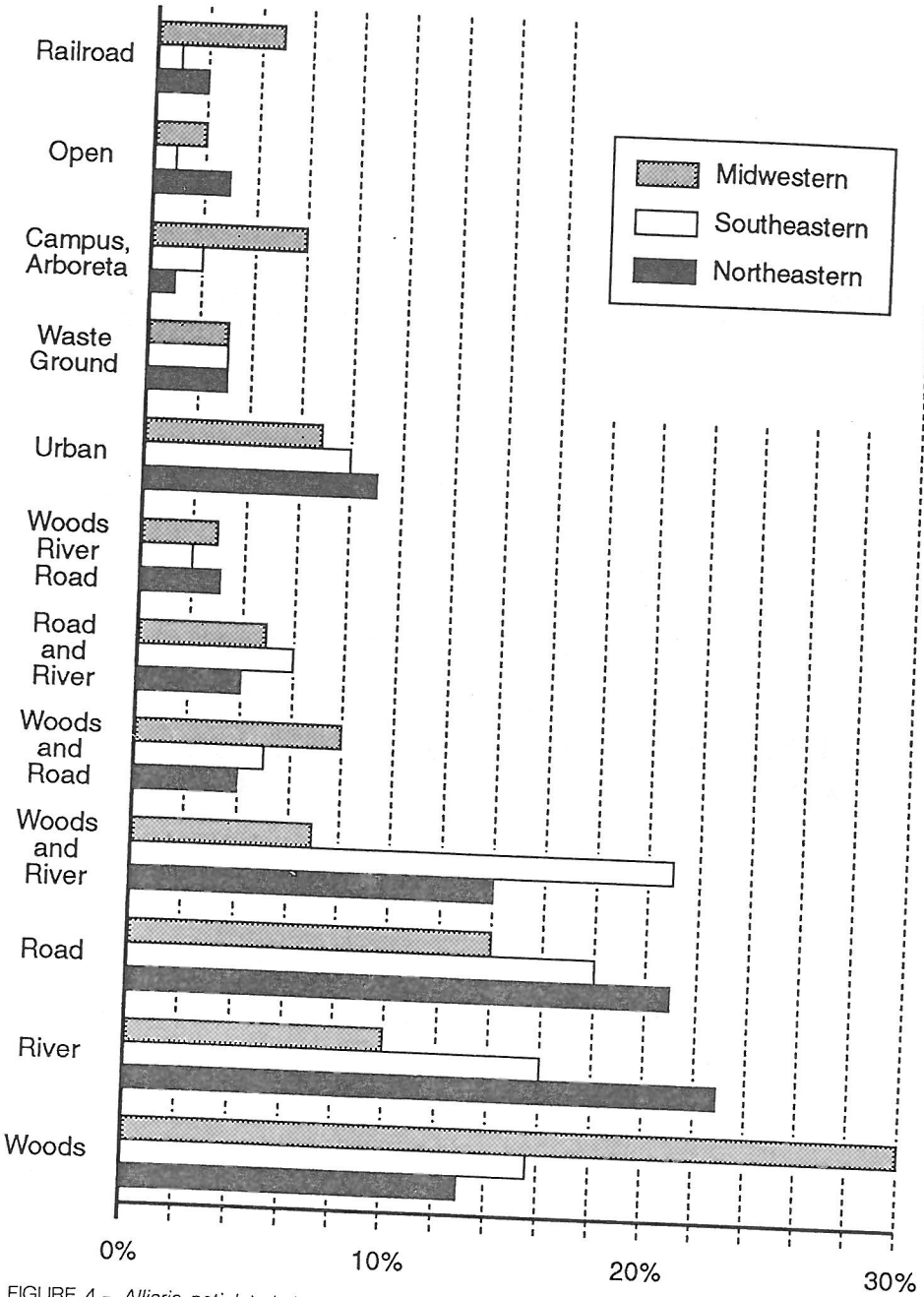

FIGURE 4.—*Alliaria petiolata* habitat by geographic region, derived from 705 herbarium specimens of *Alliaria petiolata* collected in the United States between 1868 and 1989. Northeastern states are Conn., Del., Mass., Md., Maine, N.H., N.J., N.Y., Pa., Vt., and the District of Columbia; southeastern states are Ky., N.C., Va., and W.Va.; Midwestern states are Ill., Ind., Iowa, Kans., Mich., Minn., Mo., Ohio, and Wis. Percentages based on total number of collections within each region.

Annual monitoring for and immediate removal of *Alliaria* will prevent establishment in individual natural areas. Once the species is well-established in a site, successful removal is unlikely without considerable expenditure of labor and

money (*sensu* MacDonald et al. 1989; Coblentz 1990) over an extended period of time (*sensu* Usher 1988). In regions with multiple infestations, the frequency and abundance of *Alliaria* in unmanaged habitats limit the effectiveness of single-site management, as seeds are continually imported into the managed site.

Long-term effective control will require significant reduction or elimination of *Alliaria* populations from both public and private lands throughout the infested region. Auld et al. (1978) theorize that 20 percent of a weed's populations must be eliminated annually over a 20-year period in order to eradicate the species; elimination of 5 percent of the populations will not slow the rate of spread, and at least 15 percent of all infested sites must be managed to effect an immediate decrease in the total numbers of the weed species. Successful control of *Alliaria* at this level is unlikely with current management techniques and budgets. Development and implementation of biological control agents provide the most likely means to effectively reduce presence of *Alliaria* in the northcentral U.S. and adjacent Canada.

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