WRITTEN FINDINGS OF THE
WASHINGTON STATE NOXIOUS WEED CONTROL BOARD
(1999, updated April 2008)

Scientific name: *Alliaria petiolata* (Bieb.) Cavara & Grande

Synonyms: SY=*Alliaria alliaria* (L.) Britt.
SY=*Alliaria officinalis* Andrz. *ex* Bieb.
SY=*Erysimum alliaria* L.
SY=*Sisymbrium alliaria* (L.) Scop.

Common name: garlic mustard

Family: Brassicaceae

Legal Status: Class A

Description and Variation:

Overall Habit: Garlic mustard is considered an obligate biennial herb in North America (Cavers et al. 1979; Nuzzo 1991), although it is also described as a winter annual in other areas of its range. The seeds of garlic mustard overwinter the first year. Germination and growth of the basal rosette begin early the following spring. The rosette overwinters the second year. The flowering stalk bolts early in the spring, and garlic mustard stands an erect 3 feet tall. At this time the basal rosette often withers. The overall plant is sparsely pubescent with simple hairs. The new leaves and the root have a strong garlic odor. This odor fades as the plant matures. During the rosette stage, garlic mustard resembles several native plants found in the shaded forest understory: *Viola* ssp., and several plants in the Saxifrage family, including *Tellima grandiflora* (fringecup) and *Tolmiea menziesii* (piggy-back plant). A distinguishing characteristic of the Saxifrage family is the presence of long hair, particularly on the leaf stems, which mature garlic mustard does not have.

Roots/Rhizomes: The white taproot is slender, and forms an “s” shaped curve just below the crown (Nuzzo). Axillary buds are found at the root crown, and along the upper part of the “s”.

Stem: Once the plant bolts, the stem is an erect 3 feet tall. The bolted plant generally has a single stalk, though it is sometimes slightly branched.

Leaves: The rosettes have stalked, reniform (kidney shaped) leaves. The leaves range from 2 to 8 inches long, and the leaf margins are coarse, round and irregularly toothed. On the bolted plant, the upper leaves are alternate, and their shape is deltoid (triangular), with the leaves gradually becoming narrower and smaller and sessile.

Flowers: The white flowers have four sepals, four petals about 6 mm long (twice as long as the sepals) and tetradynamous stamens (4 tall and 2 short stamens). Small nectaries are found at the base of the stamens (Cruden et al. 1996 *in* Anderson et al. 1996). The inflorescence is usually a terminal raceme, with occasional axillary racemes.

Fruits and Seeds: The fruit is a linear, 4-angled silique, from 1 to 2 ½ inches long, containing a single row of seeds. The black seeds are oblong, and grooved, with an impermeable seed coat. Seed production ranges from 194 to 8,000 seeds per plant, and seed production is density dependent.

Habitat: In its native range, garlic mustard is considered weedy, and takes advantage of disturbed areas. This species is often found in open disturbed forests and along fence rows.

In North America, garlic mustard is found in a wide variety of habitats, including many disturbed areas such as forest edges, shaded roadsides, urban areas, riparian areas, flood plains, along hiking trails, waste areas and in dry, sunny areas along railroads (Nuzzo 1993). Garlic mustard is also found in intact forests, possibly accessing them by way of micro-site disturbances (Anderson 1996). Garlic mustard grows on sand, loam, clay soils, limestone and sandstone substrates, drained peat soil and in well fertilized sites (Nuzzo 1993).

In Washington, garlic mustard is found in the shaded forest understory of several parks in the Seattle area of King County. Associated shade tolerant species include: *Tolmiea menziesii* (piggy-back plant), *Tellima grandiflora* (fringecup), *Geranium robertianum* (herb Robert), *Lapsana communis* (nipplewort) and *Hedera helix* (ivy).

Geographic Distribution: Garlic mustard is native to Europe, and is more common in northern Europe. It has since spread to North Africa, India, New Zealand, Canada and the US.

Distribution in North America: This plant was first collected in the United States from Long Island, NY in 1868. It may have been brought over for food, or for medicinal use. The largest North American populations are in New England and in the Midwest, where this species is known from 30 states and 3 provinces. Herbarium collections from the western states indicate sporadic populations, and early collections of garlic mustard are recorded from Idaho (1892) and Portland, Oregon (1959). Garlic mustard is found in western Canada, where it is established in Victoria, BC and Vancouver (Cavers et al. 1979 and White et al. 1993 *in* Nuzzo). However, Roy Cranston, Provincial Weed Specialist, BC, indicates that he is unaware of this species in the Victoria, or Vancouver area. There is an unconfirmed siting in the Okanogan (Vernon) area. (Personal correspondence 7/99).

History and Distribution in Washington: Garlic mustard was identified and first reported to the Washington State Noxious Weed Control Board in the spring of 1999, when Sarah Reichard recommended that it be listed as a Class A noxious weed. No herbarium specimens were found from the University of Washington or from Washington State University. At this time, the known locations of garlic mustard are limited to King County, with field infestations at the Woodland Park Zoo, Carkeek Park and Golden Gardens. An additional roadside site was identified in Snohomish County but was not confirmed to be A. petiolata (S. Gohrman, pers. comm.). Additional sites have been recently detected in Clark and Skamania counties.

Biology:

Growth and Development:

After a period of dormancy, germination occurs from late February or early March and lasts until May. Germination can occur in light or under the dark forest canopy. The seedlings develop into basal rosettes by mid summer, and garlic mustard overwinters as a basal rosette. The rosettes will continue to grow during the winter months, when temperatures are above freezing and there is no snow on the ground (Cavers et al. 1979). By remaining photosynthetically active through the winter, garlic mustard is able to harvest winter sunlight while other plants lie dormant. The rosette form keeps the plant close to the ground, which is the warmest part of the deciduous forest prior to spring's canopy closure. Once the trees have leafed out, garlic mustard changes form and bolts. It grows a tall stalk and sports larger, shade-adapted leaves. This form is better able to harvest light under a closed canopy and is also able to prevent light from reaching the native spring flora (Anderson et al. 1996, Myers and Anderson 2003 in Myers et al. 2005). Some vigorous plants produce up to 12 flowering stalks. Depending on the site, flower production begins in May, and seed production occurs from June to October (Anderson et al. 1996; Nuzzo; Post 1995). The seeds gradually drop from the mature siliques (Cavers et al. 1979). An average plant produces about 350 seeds per plant, but a robust plant can produce up to 8,000 seeds. Seed production per site ranges from 9,533 seeds/m² to 107,580/m² (Anderson et al. 1996). Seeds can remain in the seed bank for 5 years, though most germinate during the first two years (Baskin and Baskin 1992 *in* Bartuszevige et al. 2007). After one year in the soil, only 10% of seeds are still viable (Drayton and Primack 1999 *in* Frey et al. 2007). The populations are never constant because of the differing germination rates of the seeds. The seeds have grooves that trap air, equipping them for short-term wind dispersal (Post 1995). While seed often falls close to the parent plant, Nuzzo (1999) determined that garlic mustard seed travels an average of 5.4 m/year in Illinois, in part from the force of the exploding capsules, and in part from human and animal transport.

While germination rates for seeds are high, seedling mortality is also high, with only 7.5% seedling survival. The survival rates from seedling to mature plant range from 1% (Nuzzo 1993b) to 2% - 4% (Cavers et al. 1979). Summer drought can cause 95% mortality of first year rosettes (Nuzzo). High density rates may help to offset the high seedling mortality rates, and it may help with competitiveness during the second year of growth (Anderson et al. 1996). Mortality during the second growing season is low. A population density study revealed that garlic mustard plants growing in lower density plots (4 rosettes/.5m x .5m) are larger and yield more fruits than those growing in medium density (10 rosettes/.5m x .5m) or high density (20 rosettes/.5m x .5m) plots. Plants in low-density plots also have a better chance of surviving until flowering than plants in the other plots (Meekins and McCarthy 2002). Consistent with these findings, Susko and Lovett-Doust (2000) found that larger plants produced more seeds than smaller plants.

Large seeds become seedlings with greater mass, while smaller seeds germinate and become seedlings with less mass. Smaller seeds tend to germinate sooner than larger seeds, and also grow taller, suggesting that they compensate for reduced reserves by getting a head start – both temporally and spatially. The tendency for smaller seeds to lengthen sooner may also help the plant to establish when seeds are buried, a likely scenario in disturbed areas (Susko and Lovett-Doust 2000).

Meekins and McCarthy (2000) explored variations in population density, nutrient addition and light availability on garlic mustard grown in a garden. While each parameter had some impact, light availability had the greatest impact on the growth and spread of both rosettes and mature plants.

Garlic mustard plants in the U.S. are as much as eight times smaller than plants in the native range of Hungary, and experience less herbivory. They also produce fewer seeds than plants in the native range, but when plants of the same size are compared, the U.S garlic mustard produced larger seeds than the Hungarian plants (Lewis et al. 2006).

Reproduction:

In North America, garlic mustard is considered an obligate biennial herb that reproduces by seed. Garlic mustard is capable of cross-pollination and self-pollination, producing individual plants that are genetically similar and interfertile. Most populations of garlic mustard are autogamous, with self-pollination occurring before the flowers open and before the stigma is exposed. Local populations exhibit variations in pollination and breeding systems, probably due to genetic differences in the floral biology (Anderson et al. 1996).

Control:

Response to Herbicide:

Glyphosate at rates from 1% to 3% applied to rosettes in late fall or early spring reduced adult cover by 95% (Nuzzo date?). Glyphosate mixed with 2,4-D amine can also be effective applied in spring and fall. Bentazon has shown good activity applied in mid-summer on first year rosettes growing in dense stands. There is no known chemical control for the seedbank (Haber 1997). Please refer to herbicide labels for site-specific control information.

Several studies found that application of glyphosate to garlic mustard rosettes in the winter provided good control at a time when native plants are dormant and more tolerant of glyphosate. Scott (2005) found that 1% glyphosate mixed with ammonium sulfate can be effective even when air temperatures are at or just below freezing, as long as there is no snow on the plants and precipitation does not occur for the two hours following the treatment. However, Slaughter et al. (2007) found that new seedlings emerged following established plant removal, perhaps from seed arising in adjacent plots, which ultimately resulted in dense garlic mustard stands after five years. They therefore concluded that glyphosate should be used over the entire treatment area if effective control of garlic mustard rosettes in the winter is desired, Slaughter et al. Garlic mustard survival is improved when seedlings are not intermixed with adults (Winterer et al. 2005). Slaughter et al. also found that garlic mustard seed germination and resultant seedling survival was greater in wet years than in dry. This is consistent with other studies that found that garlic mustard infestations were more extensive in moist lowlands than in the drier uplands (Byers and Quinn 1998; Meekins and McCarthy 2001; both *in* Slaughter et al. 2007) and that rosettes tended to die in dry summers

(Byers and Quinn 1998 *in* Slaughter et al. 2007).

Response to Cultural Methods: Prescribed burnings for large sites are a control option, and burning for 2 consecutive years is recommended, and effective. This will reduce the rosette populations. Fires as a management tool are not always an option, though, and they do have their drawbacks – namely regeneration of flowering stalks from the root crown if the fires are not hot enough, which leads to higher seed production, and high rates of seedling survival after a fire (Nuzzo date?).

Garlic mustard establishment and survival is negatively affected by leaf mulch, indicating that mulching garlic mustard could be an effective way to contain the species. In a woodlot in Ohio, more seeds germinated in patches of bare ground than in patches with leaf mulch (Bartuszevige et al. 2007). Seedlings had a better survival rate in leaf mulch than on bare ground, although overall seedling numbers were greatest in patches of bare ground. When mulch depth was doubled, seedling establishment dropped, suggesting that increasing mulch depth can also reduce seedling establishment. This finding is supported by Meekins and McCarthy (2001 *in* Bartuszevige et al. 2007) who found that garlic mustard had greater establishment in the forested lowlands and edges than in the more litter-rich uplands.

Some control has been achieved by interplanting *Sanguinaria canadensis* into infestations of *A. petiolata* (Murphy 2005). When patches were interplanted with various densities of *S. canadensis* ramets, those with 7, 9 and 11 ramets/m^2 were found to be most successful at suppressing a number of garlic mustard growth measurements over four years. These measurements included the number of flowers and siliques, the height at final flowering, the number of stem leaves and the total leaf area. Total number of seedlings was not affected, however. *S. canadensis* was chosen for this study because the time period during which it leafs out overlaps with that of *A. petiolata*, and the researcher had observed it holding its own amid garlic mustard infestations. In addition, the shoots grow quickly and the leaves are relatively large (Marino et al. 1997 *in* Murphy 2005). S. Canadensis is not native in Washington; however, it is possible that a native species with similar attributes could be utilized in this way.

Response to Mechanical Methods: Depending on the size of the infestation, hand pulling is an effective control for this short-lived mustard. Mature plants are easily pulled. The rosettes tend to snap off at the root (personal observation) Does this imply good control?. Another option is to cut the flowering stalk to only a few inches above the ground, just before the plant produces flowers. Remove these stems from the site. The site should be monitored for 2 to 5 years, until the seed bank is eliminated.

Hand pulling 50% of the garlic mustard in a plot may be more beneficial than pulling all of the plants, perhaps because of the disturbance caused by so much removal. Ash and sugar maple showed a trend (though not significant) toward increasing numbers when 50% of the garlic mustard was removed, and a slight decline when all of the plants were removed. White wood aster (*Aster divaricatus*) and Appalachian sedge (*Carex appalachica*) increased when all of the garlic mustard was removed, while other plants didn't respond well to the removal. Black cherry (*Prunus* *serrotina*), old man's whiskers (*Geum triflorum* and Dewey sedge (*Carex deweyana*) became less abundant following both 50% and complete removal of garlic mustard. Hand pulling in a given area over time may result in better regeneration of certain desirable natives, and tree seedlings in particular. How much to hand pull depends on the management goals: if species diversity is desired, then pull all of the plants; if certain taxa are targeted, in particular certain tree species, and richness is valued, then a partial pull may yield the best results (Stinson et al. 2007).

Biological Control Potential: The preliminary research for a potential biological control project of garlic mustard was initiated by Bernd Blossey in April 1998. A literature review reported 69 insects and 7 fungi as natural predators. 26 of those species were collected, 17 species were reared, and 6 species were selected as potential biocontrol agents: *Ceutorhyitchus alliariae* and *C. roberti*, shoot-mining weevils that attack rosettes and bolting plants; *Ceutorhynchus constrictus* which has larvae that destroys seeds; *Phyllotreta ochripes,* a flea beetle larvae that mines the root and root crown; *Ophiomyia alliariae* a shoot-mining agromyzid; and another weevil, *Ceutorhynchus scrobicollis*, which feeds on rosettes (Hinz, H.L. and E. Gerber 1998). In Davis et al. (2006), researchers used demographic parameters of garlic mustard to determine which stages in the life cycle of the plant, if impacted by herbivory, would be most effective at reducing the population. They modeled the impacts of the four weevil species in the genus *Ceutorhynchus* that were being considered for biocontrol. They concluded that herbivory during the rosette stage and damage that reduces seed set would have the greatest impact on the garlic mustard population, and predicted that the root-crown feeder, *C. scrobicollis*, would do the most damage to garlic mustard. Given the demographic variability of garlic mustard and the different ecological niches that it occupies, the researchers predicted that biocontrol would be effective in some infestations of garlic mustard, but not all. They also predicted that biocontrol would need to attack the plant on several fronts in order to be effective. In 2007, Blossey et al. conducted experiments with two of these weevils, *Ceutorhynchus scrobicollis* and *Ceutorhynchus alliariae*, and found that *C. scrobicollis* significantly increased plant mortality, while the significant impacts of *C. alliariae* was limited to reduced plant height.

To varying degrees, garlic mustard in Ohio forests is infected by a powdery mildew, *Erysiphe cruciferarum* (Erysiphaceae). Field studies of second year plants revealed that plants that are heavily infected with the fungus have significantly fewer siliques and produce half as many seeds as the plants with little incidence of the powdery mildew. Germination rates were not affected (Enright and Cipollini 2007).

Several viruses do affect *Alliaria*, but only under certain conditions – and they did not affect plants growing in a natural environment (Nuzzo).

Economic Importance:

Detrimental: Garlic mustard is broad-niched, has a short life cycle, and can self-pollinate –in short, it has an invasive biology (Bazzaz 1986 *in* Anderson et al. 1996). Seedlings establish in areas that have experienced some kind of disturbance. While the disturbance can occur in places that are typically considered disturbed – forest edges, roadsides – they may also take the form of "micro-site" disturbances (Anderson et al. 1996), or small patches in the intact forest that clear the leaf litter, exposing bare soil (Bartuszevige et al. 2007). In this way, garlic mustard is able to gain entry into a relatively stable forest understory habitat, and replace the existing vegetation. In fact, Nuzzo (1999) found that garlic mustard cover declined when there wasn't any disturbance, although Meekins and McCarthy (2001 *in* Bartuszevige et al. 2007) did not find an increase in germination, growth or reproduction when they removed leaf litter in the vicinity of garlic mustard. This exotic species is a winter annual/biennial, with vegetative growth starting early in the season, outcompeting native and beneficial species that are still dormant at this time of year. Since garlic mustard is able to self-pollinate, one plant has the capability to take over an entire site. By forming monospecific stands, garlic mustard disrupts and threatens native ecosystems, causing increased concern for resource managers. Natural areas that are managed, or preserved, are at risk of garlic mustard outcompeting and replacing the existing vegetation (Anderson et al. 1996). Once established, garlic mustard is difficult to eradicate. There are no known natural predators. The infestation size of garlic mustard can double in four years. In areas of high disturbance the population size can increase from 214% (flood zone) to 1000% (canopy loss in forest windstorm) in 2 years (Nuzzo).

Garlic mustard has antifungal properties, as does other members of the Brassicaceae family. It produces glucosinolates (Vaughn and Berhow 1999 *in* Hochstedler et al. 2007) and may produce other compounds that show up in the soil by way of leaf litter (Stinson et al. 2006) or root exudates (Prati and Bossdorf 2004 *in* Hochstedler et al. 2007). A glucosinolate called glucotropaeolin is found at much higher concentrations in the roots of rosettes than adults (Vaughn and Berhow 1999 *in* Hochstedler et al. 2007), suggesting that rosettes could be more deleterious to other flora than mature garlic mustard. Also, the concentration of glucotropaeolin in garlic mustard roots harvested in the autumn is more than three times the concentration found in spring-harvested roots (Vaughn and Berhow 1999). However, the relationship between glucotropaeolin and the antifungal properties of the root exudates is unknown (Stinson et al. 2006). Garlic mustard does disrupt certain plant-mycorrhizal fungi (AMF) connections, which may explain the greater impact that it has on certain tree seedlings. By reducing recruitment of particular tree species, garlic mustard can change the composition of the overstory as well as the understory that it invades. Graminoids and specific forbes are also negatively affected by garlic mustard (Stinson et al. 2007). Low levels of herbivory, fungal disruptions and allelopathic effects on other plants may also be a result of the cyanide that garlic mustard produces. Cyanide can interfere with the biological activity of plants, animals, and microbes (Jones 1998; Blenis et al., 2004; Gonzales and Sotomayor 2005; all *in* Cipollini and Gruner 2007). Cyanide levels in garlic mustard can reach 100 ppm, fresh weight, which can be toxic to numerous vertebrates. Cyanide levels were highest in garlic mustard seedlings, and decreased as the plants aged (Cipollini and Gruner 2007).

Keeler et al. (2006) simulated the population dynamics of the native mustard white butterfly, *Pieris napi oleracea* Harris, and found that the greatest threat to the already depleted population is garlic mustard, as it replaces plants that the butterfly would use for ovipositing and larval development. Garlic mustard contains alliarinoside, which inhibits feeding by the butterfly's early instar larvae (Haribal et al. 2001). When garlic mustard reaches 50% cover in the butterfly's habitat, the probability that the butterfly will persist drops to zero (Keeler et al. 2006). In Europe, *Alliaria* is the host plant for the *Alliaria* mosaic virus (Cavers et al. 1979) and several viruses affecting horticultural and agricultural crucifers (Nuzzo). Canadian farmers report that when cattle eat the rosettes of garlic mustard, the milk is tainted and has a bad taste to it (Cavers et al. 1979).

Beneficial: As a winter herb, garlic mustard is used in salads and as a garlic or onion substitute for recipes (Post 1995). It is high in Vitamins A and C. It contains antiseptic properties and was used to clean wounds and abrasions.

Rationale for Listing:
Garlic mustard is a shade tolerant, invasive species with the capability to establish in our state. This exotic species has a history of invading and establishing, at a very fast rate, in the forested habitat of the New England area and Midwestern states, causing expensive and long-term management problems of natural areas. The biology of garlic mustard makes it difficult to control once it has reached a site: it is self-fertile, has a high seed production rate, outcompetes native vegetation by germinating early in the spring and can establish in a relatively stable forest understory. Because it is it self-fertile, one plant can occupy a site, produce a seed bank and create a new infestation of garlic mustard.

Prevention is often mentioned as the recommended control method for garlic mustard. At this time, the known distribution of garlic mustard in our state is very limited. By listing this species as a Class A noxious weed, and requiring eradication, we have the potential to contain the spread of garlic mustard and remove any existing populations.

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