Garry oak ecosystems recovery team

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Bibliographic summary of the Ecology and Management of Invasive Species:

Ailanthus altissima

Tree of Heaven

Prepared by

Marian McCoy, Melica Environmental, Victoria, BC

for the Garry Oak Ecosystems Recovery Team

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Peer-reviewed journal articles

Albright, T.P., H. Chen, L. Chen, and Q. Guo. 2010. The ecological niche and reciprocal prediction of the disjunct distribution of an invasive species: the example of *Ailanthus altissima.* Biol Inv., Vol. 12, No. 8, pp. 2413-2427.

> Authors' abstract: Knowledge of the ecological niches of invasive species in native and introduced ranges can inform management as well as ecological and evolutionary theory. Here, we identified and compared factors associated with the distribution of an invasive tree, *Ailanthus altissima*, in both its native Chinese and introduced US ranges and predicted potential US distribution. For both ranges separately, we selected suites of the most parsimonious logistic regression models of occurrence based on environmental variables and evaluated these against independent data. We then incorporated information from both ranges in a simple Bayesian model to predict the potential US distribution. Occurrence of *A. altissima* in both ranges exhibited a unimodal response to temperature variables. In China, occurrence had negative relationships with topographic wetness and forest cover and positive relationships with precipitation and agricultural and urban land use. In the US, *A. altissima* was associated with intermediate levels of forest cover and precipitation. The Bayesian model identified 58–80% of 10-arc minute grid cells in the conterminous US as containing suitable areas for *A. altissima*. The best model developed from Chinese data applied to the US matched most areas of observed occurrence but under-predicted occurrence in lower probability areas. This discrepancy is suggestive of a broadening of the ecological niche of *A. altissima* and may be due to such factors as less intense competition, increased potency of allelopathy, and novel genotypes formed from multiple introductions. The Bayesian model suggests that *A. altissima* has the potential to substantially expand its distribution in the US.

Aldrich, P.R., J.S. Briguglio, S.N. Kapadia, M.U. Morker, A. Rawal, P. Kalra, C.D. Huebner, G.K. Greer. 2010. Genetic Structure of the Invasive Tree Ailanthus altissima in Eastern United States Cities. J. Bot., Vol. 2010, Article ID 795735, 9 pp.

> Authors' abstract: *Ailanthus altissima* is an invasive tree from Asia. It now occurs in most US states, and although primarily an urban weed, it has become a problem in forested areas especially in the eastern states. Little is known about its genetic structure. We explore its naturalized gene pool from 28 populations, mostly of the eastern US where infestations are especially severe. Five microsatellite markers were used to examine presumed neutral genetic variation. Results show a gene pool that is moderately diverse and sexually active and has significant but small genetic differences among populations and little correspondence between geographic and genetic distance. These findings are consistent with a model of multiple introductions followed by high rates of gene exchange between cities and regions. We propose movement along road and railway systems as the chief mode of range expansion.

Burch, P.L., and S.M. Zedaker. 2003. Removing the invasive tree *Ailanthus altissima* and restoring natural cover. J Arboriculture, Vol. 29, No. 1, pp. 18-24.

> Authors' abstract: Eight herbicide treatments were applied by low volume basal applications and compared to hand cutting for the removal of *Ailanthus altissima*. Manual cutting of Ailanthus stimulated resprouting and increased overall stand density. Chemical control not only removed existing trees but also prevented resprouting. When evaluated 2 years after treatment, optimal control of *Ailanthus* was achieved with a combination of Garlon 4 and Tordon K herbicides. Garlon 4 at 20% v/v alone, Garlon 4 combined with Stalker, or Stalker herbicide alone controlled *Ailanthus* better than hand cutting but were not as effective as

treatments containing picloram. Removal of *Ailanthus* resulted in a shift in herbaceous species to native species of the region without reseeding with naturally occurring herbs. Manual control of *Ailanthus* should be avoided in order to prevent proliferation. Herbicide control of *Ailanthus* is the preferred method of control because it successfully kills the trees and prevents resprouting. Because major *Ailanthus* infestations occur near roadways, access with a backpack sprayer should be achievable.

Constán-Nava, S., A. Bonet, E. Pastor, and María José Lledó. 2010. Long-term control of the invasive tree *Ailanthus altissima*: Insights from Mediterranean protected forests. Forest Ecol. and Management. Vol 260, Issue 6, pp. 1058-1064.

Authors' abstract: *Ailanthus altissima* is an invasive tree species which has colonized numerous ecosystems and affected ecosystem processes worldwide. Despite its importance as an invasive species and the high economic costs incurred from its spread, there is a lack of long-term management planning for its control. Although mechanical disturbance is commonly applied, the effect that this treatment may have [in] exhausting its resprouting ability and also its joint effect with phytochemical treatments are poorly understood, especially in Mediterranean environments. We tested three treatments (plus a control) aimed to reduce *A. altissima* growth in Mediterranean forests throughout 5 years of study. The treatments (one cut stump, double cut stump and cut stump with glyphosate application) were repeated annually. General plant performance (biomass, height and resprout-type density) was measured yearly during the study. Water potential and stomatal conductance were also measured at the end of the study to evaluate particular ecophysiological factors which might affect the response of *A. altissima* to assayed treatments, together with leaf area index. Our results show that only the cut stump with glyphosate application treatment reduced the long-term growth and spread of *A. altissima*. The treatments applied favoured collar sprout growth in response to disturbance events (treatments) opposite to the control, where new sprouts grew mainly from the root. Treated resprouts displayed ecophysiological changes depending on the assayed treatment. To our knowledge, this is the only study testing the long-term effect of both physical disturbance and phytochemical application on *A. altissima* growth.

Fotiadis, G., A.P. Kyriazopoulos, and I. Fraggakis. 2011. The behavior of *Ailanthus altissima* and its effects on natural ecosystems. J. Environ. Biol. Vol. 32, pp. 801-806.

Authors' abstract: *Ailanthus altissima* is an invasive species for the native flora of Greece and it could pose a serious threat to the biodiversity and the functioning of ecosystems. The purpose of this study was to investigate the spreading of *Ailanthus altissima* in urban and non urban areas of North and Central Greece and also to evaluate the effects of its spreading on species composition and floristic diversity in natural ecosystems. The spreading of *Ailanthus altissima* in urban areas is very intense, mainly in abandoned places (35.29%). It is commonly found in non urban areas of Greece, especially in hedgerows of arable lands (36%) and adjacent wetlands (17%). It is less common in forests (4%), shrublands (11%) and grasslands (9%). The spread of *Ailanthus altissima* in urban and natural ecosystems is relatively recent. Although it has been recorded at altitudes of up to 640 m, it usually appears at low altitudes of up to 200 m. Floristic diversity was found to be higher in the stands that it dominated (H´=1.574, H´=1.890) in comparison to stands that were dominated by *Quercus pubescens* (H´=1.468) or *Q. coccifera* (H´=1.716). This may be contributed to the fact that in those stands synanthropic species, which are usually found in regions of intense human activity, were present together with typical forest vegetation species.

Gómez-Aparicio, L., and C.D. Canham. 2008. Neighbourhood analyses of the allelopathic effects of the invasive tree *Ailanthus altissima* in temperate forests. J. Ecol., Vol. 96, Issue 3, pp. 447-458.

Summary: We analyzed the allelopathic effects of the invasive tree *Ailanthus altissima* on seedling emergence, survival and growth of three native tree species (*Acer rubrum, A. saccharum* and *Quercus rubra*) in temperate forests of the northeastern United States. We used activated carbon (AC) to reduce potential allelopathic interference, and developed neighbourhood models that explain the observed spatial variation in the effects of the AC treatments on seedling performance as a function of the size, abundance and distribution of Ailanthus trees in the neighbourhood. Our results showed that the addition of AC to the soil did not affect seedling emergence or survival, but caused a significant increase in seedling growth of all three species. Moreover, the AC shifted the overall interaction between Ailanthus and maple seedlings from neutral or slightly positive to very positive for *A. rubrum*, and from negative to positive for *A. saccharum*, whereas the net interaction between *Ailanthus* and *Q. rubra* was always negative. As *Ailanthus* has the ability to increase soil fertility, these species-specific responses are presumably influenced by among-species differences in the net effects of both allelopathy and changes in resource availability caused by the presence of *Ailanthus*. The cumulative allelopathic effects of *Ailanthus* were proportional to the density of Ailanthus in the neighbourhood, regardless of their size. In contrast, *Ailanthus* effects were strongly influenced by distance from a tree, generally dropping to zero within 5 m from the trunk. Our results indicate that allelopathy is an important mechanism to take into account when trying to understand the causes and consequences of plant invasions. However, this study also strongly suggests that the real significance of the allelopathic effects of an invasive species cannot be assessed independently of its target community, or in isolation of other resource interactions involving the invader and the native community.

Heisey, R.M. 1996. Identification of an Allelopathic Compound from Ailanthus atltissima (Simaroubaceae) and Characterization of its Herbicidal Activity. Am. J of Botany, Vol. 83, No. 2, pp. 192-200.

Author's abstract: Aqueous extracts of *Ailanthus altissima* bark and foliage were previously shown to be toxic to other plants. Using bioassay-directed fractionation, I isolated the phytotoxic compound from *A. altissima* root bark and identified it to be ailanthone, a quassinoid compound having molecular mass of 376. Ailanthone was highly phytotoxic, with concentrations of 0.7 ml/L causing 50% inhibition of radicle elongation in a standardized bioassay with garden cress (*Lepidium sativum*) seeds. Ailanthone exhibited potent pre- and postemergence herbicidal activity in greenhouse trials. Postemergence activity was especially striking; even the lowest application rate (0.5 kg/ha) caused complete mortality of five of the seven plant species tested within 5 d of treatment. In contrast, the highest application rate (8 kg/ha) did not cause any detectable injury to *A. altissima* seedlings, indicating the presence of a protective mechanism in the producer species to prevent autotoxicity. Ailanthone was rapidly detoxified in field soil as a result of microbial activity. Applications of ailanthone equivalent to 0.5 and 4.0 kg/ha completely lost their phytotoxicity within ≤5 d when incubated in the presence of nonsterile soil. When incubated with sterile soil under identical conditions, however, ailanthone remained highly phytotoxic throughout the 21-d duration of the investigation. The high level of postemergence herbicidal activity in conjunction with its rapid biodegradation in soil suggest ailanthone may have potential for development as a natural-product herbicide.

Knapp, L.B., C.D. Canham. 2000. Invasive of an old-growth forest in New York by *Ailanthus altissima*: sapling growth and recruitment in canopy gaps. J of the Torrey Botanical Society. Vol. 127, No. 4, pp. 307-315.

Authors' abstract: The exotic tree *Ailanthus altissima* is known to invade open and disturbed sites. As a shade-intolerant species, it is not generally identified as a potential invader of forests. Nevertheless, *Ailanthus* saplings dominate several natural gaps within Montgomery Place South Woods, a small old-growth hemlock-hardwoods forest in the Hudson Valley region of New York State. Within these gaps, the height, diameter, and extension growth of the tallest *Ailanthus* saplings are significantly greater than those of the tallest native competitors. Although *Ailanthus* is absent from fully shaded availability. Pole-sized *Ailanthus* within South Woods exhibit a history of high annual radial growth, with means for individual trees ranging from 1.96 – 3.70 mm / yr. These results support the hypothesis that *Ailanthus* established in old-growth gaps can reach the canopy by virtue of rapid growth during a single period of release. *Ailanthus* thus exhibits a "gap-obligate" strategy of forest recruitment.

Kowarik, I. 2009. Clonal growth in *Ailanthus altissima* on a natural site in West Virginia. J of Veg Sci., Nol. 6, Issue 6, pp. 853-856.

Author's abstract: The exotic tree *Ailanthus altissima* is usually confined to open sites. As an exception, *Ailanthus* established in a densely closed forest in West Virginia, which was analyzed with the aim to elucidate possible pathways of persistence in forest succession of this light-demanding pioneer species. Demographic analysis revealed a seedling mortality of 100%. Instead, the understory is populated by clonal ramets, ranging from one to more than 19 years of age, with a mean of 5 years. Growth averages only 0.11 m/yr, and height is correlated with age. This clonal growth contrasts with the performance of *Ailanthus* on open sites. The possible ecological benefits of establishing a ramet bank in a resource-poor habitat are considered in terms of space occupation of a pioneer species.

Kowarik, I., and I. Säumel. 2008. Water dispersal as an additional pathway to invasions by the primarily wind-dispersed tree *Ailanthus altissima.* Plant Biol. Vol. 198, No. 2, pp. 241-252.

Authors' abstract: Long-distance dispersal is a key process in biological invasions. Previous research has emphasized the role of nonstandard dispersal vectors, but consequences of a change in dispersal vector for the establishment of invasive plant species have received less attention. We analyzed how water-mediated dispersal rather than the more expected wind-mediated dispersal can affect the establishment of the invasive tree *Ailanthus altissima* in riparian corridors by changing the germination rate and velocity and by providing the option of a new pathway of vegetative propagation. We analyzed the potential of different types of propagules (fruits that have floated or been submerged, current- and second-year stem fragments) to establish new individuals after contact with water for 0, 3, 10, and 20 days. Length and type of seed contact with water led to divergent germination responses. Seeds that had floated for 3 days had an increased level of seed germination (87%), while a 20-day stay in water water-curbed germination to 32% compared to 53% in control. After floatation, the maximum number of emerged seedlings was achieved more than 3 weeks earlier than in all other treatments. In general, the germination was enhanced in floating compared to submerged fruits. Experiments with stem fragments revealed the option of a novel pathway for long-distance dispersal in river corridors: Except for stem fragments that floated for 20 days, 33–75% of buried stem fragments produced adventitious shoots, 10% also set roots. The results suggest that both generative and vegetative propagules of *A. altissima* can be dispersed at regional scales in river corridors. Hence, water as an additional dispersal vector is expected to enhance invasions by species with wind-dispersed seeds. Our findings suggest the importance of control of initial colonizations in riparian habitats and emphasize the need to include consequences of secondary dispersal when modeling the spread of invasive species.

Kowarik, I., and I. Säumel. 2007. Biological flora of Central Europe: *Ailanthus altissima* (Mill.) Swingle. Perspectives in Plant Ecology, Evolution and Systematics. Vol. 8, issue 4, pp. 207-237.

Authors' abstract: *Ailanthus altissima* (tree of heaven), Simaroubaceae, is an early successional tree, native to China and North Vietnam, which has become invasive in Europe and on all other continents except Antarctica. It is most abundant in urban habitats and along transportation corridors, but can also invade natural habitats. This paper reviews the literature on the morphology, distribution, ecology, habitat requirements, population biology, genetics, physiology, impacts, management and uses of this species.

Landenberger, R.E., T.A. Warner, and J.B. McGraw. 2009. Spatial patters of female *Ailanthus altissima* across an urban-to-rural land use gradient. Urban Ecosystems, Vol. 12, No. 4, pp. 437-448.

Authors' abstract: *Ailanthus altissima* is an invasive, dioecious deciduous tree common at the interface between urban and rural areas in the mid-Atlantic region, U.S.A. To examine spatial patterns of abundance and associations with land use type, we mapped all mature female trees in nine 89.5 ha plots (805.5 ha total area) across a typical urban-to-rural land use gradient using aerial images obtained via remote sensing supplemented by detailed ground referencing. Rural plots were dominated by forest and had the lowest density of mature females (0.007 females ha−1); urban and suburban plots did not differ significantly in mean density (0.37 females ha−1 vs. 0.34 females ha−1, respectively). Individuals in urban plots were more evenly distributed, but were not associated with a wider variety of land uses and were closer to roads or openings than those in suburban plots. Given less available habitat per unit area in urban than in suburban environments, these patterns suggest that Ailanthus fits the profile of an invasive species that may be proliferating outward from urban centers. With continued disturbances associated with development in the suburban areas, and timber harvesting in the rural areas, further spread of *Ailanthus* seems likely.

Lawrence, J.G., A.L. Colwell, and O.J.Sexton.1991. The Ecological Impact of Allelopathy in *Ailanthus altissima* (Simaroubaceae). Am J of Botany, Vol. 78, No. 7, pp. 948-958..

Authors' abstract: Compounds inhibitory to the growth of neighboring plant species were found in significant concentrations in the leaves and stems of young *Ailanthus altissima* ramets. The surrounding soil also contained appreciable concentrations of similarly acting toxins. Individuals of neighboring plant species have either incorporated active portions of inhibitory compounds or responded to *Ailanthus* by producing growth-inhibiting substances. Under greenhouse conditions, individuals of neighboring plant species previously unexposed to *Ailanthus* in the field were found to be more susceptible to the *Ailanthus* toxins than individuals previously exposed. Moreover, seeds produced by unexposed populations were also more susceptible to *Ailanthis* toxins than seeds produced by previously exposed populations. These differences demonstrated that the allelochemicals of *Ailanthus altissima* exhibited a measurable impact upon neighboring plant species. Since the progeny of these populations displayed a differential response to *Ailanthus* toxin, this phenotypic difference between the two populations may have a heritable basis.

Meloche, C., and S.D. Murphy. 2006. Managing Tree-of-Heaven (*Ailanthus altissima*) is Parks and Protected Areas: A Case Study of Rondeau Provincial Park (Ontario, Canada). Vol. 37, No., 6, pp. 764-772.

Authors' abstract: The Carolinian Life Zone in southwestern Ontario, Canada is valued because it represents an almost disjunct ecosystem (i.e., one that is typical of the mid-Atlantic United States, rather than the rest of Canada or the nearby states in the United States). The landscape of the Carolinian Life Zone has undergone dramatic transformation, especially in recent decades as agriculture, urbanization, and recreation have intensified. One of the most apparent changes is the invasion of exotic plant species that exacerbates

the need for mass restoration efforts. Within the Carolinian Life Zone, Rondeau Provincial Park has experienced an influx of nonindigenous, invasive species in recent years. Tree-of-heaven (*Ailanthus altissima*) is one example. The infestation is still relatively localized to (mainly) the park, slowly spreading, and manageable as long as something is done immediately. We examined the effects of hand-pulling and mulching, cut stump and glyphosate application, cut stump alone, and the EZJect Capsule Injection System (using glyphosate) on the management of *A. altissima* within the park. Cut stump and glyphosate treatment was most effective and efficient in its control of young *A. altissima* shoots because it limits disturbance and has acceptable capital and operating costs. Hand-pulling and mulching was the second choice, mainly because of the risk of additional disturbance that increased shoot densities 1 year after treatment. Cut stump alone was not effective, worsened the infestation, and is not recommended for this species. The EZJect system was effective at managing mature, seed-producing shoots, although the somewhat higher capital costs mean that the system probably should be purchased for management of several invasive tree species to make it more cost-effective.

Motard, E., A. Muratet, D. Clair-Maczulajtys, and N. Machon. 2011. Does the invasive species Ailanthus altissima threaten floristic diversity of temperate peri-urban forests? Comptes Rendus Biologies, Vol. 334, Issue 12, pp. 872-879.

Authors' abstract: We examined the influence of the invasive species *Ailanthus altissima* (Mill.) Swingle on the understory of the Fontainebleau forest, a peri-urban forest of Paris (France), by comparing invaded versus control plots. We performed floristic inventories in fixed plots around the base of *A. altissima* versus native trees in different habitat types of the forest. Our findings suggest that the understory vegetation is significantly poorer and more common under *A. altissima* than under the other tree species and that the floristic composition is significantly different. Furthermore, the number of *A. altissima* root suckers growing in the plots was significantly negatively correlated with floristic richness. This effect can be attributed to both interspecific competition and allelopathic properties of *A. altissima*. These results give an estimate of the threat to biodiversity ascribed to *A. altissima* in the Fontainebleau forest.

Säumel, I., and I. Kowarik. 2009. Urban rivers as dispersal corridors for primarily wind-dispersed invasive tree species. Landscape and Urban Planning. Vol. 94, Issues 2-4, pp. 244-249.

Authors' abstract: Urbanization may have a large effect on biodiversity patterns by enhancing biological invasions. Urban habitats harbour high numbers of introduced plant species and may function as starting points for invasions along urban–rural gradients. As information on underlying mechanisms is critical for managing biological invasions, we test the role of rivers as dispersal corridors for primarily wind-dispersed ornamentals. We released tagged fruits of three invasive tree species in the Spree River (Berlin, Germany) and directly observed the fate of the floating samaras. The number of floating samaras declined exponentially with distance from the release point. A quarter floated 1200m within 3 h. Despite marked differences in fruit morphology, there were no interspecific differences in floating capacity. We showed hydrochory to be an effective dispersal agent in wind-dispersed tree species, extending wind-related transport distances by several times. In this way, rivers are expected to link urban propagule sources with natural habitats downstream. Our results suggest that planting native tree species along river corridors would help prevent invasion risks and contribute to implementing principles of ecological design in urban greenways and generally consider the importance of eradicating wind-dispersed invasive tree species in floodplains in early invasion stages to prevent further water-mediated dispersal.

Small C.J., D.C. White, and B. Hargbol. 2010. Allelopathic influences of the invasive *Ailanthus altissima* on a native and a non-native herb. J of the Torrey Botanical Society. Vol. 137, No. 4, pp. 366-372.

Authors' abstract: As a highly aggressive non-native invasive and an allelopathic species, *Ailanthus altissima* (tree of heaven) has the capacity to negatively affect native plant communities by suppressing resident species and altering competitive interactions. We examined effects of *A. altissima* on the establishment and growth of two herbaceous species common in invaded natural areas. Soil samples were collected from six replicate A. altissima-dominated stands and six control stands (no *A. altissima* present) in the Appalachian Ridge and Valley province of southwestern Virginia. Two target species, *Verbesina occidentalis*, native to the southeastern US, and *Dipsacus fullonum*, non-native and invasive throughout North America, were selected for their high germination success and contrasting native vs. invasive status. Germination and growth of target species were monitored in greenhouse flats for six weeks. We found severe reductions in all measured aspects of *V. occidentalis* when grown in Ailanthus versus control soils, including seed germination ($P = 0.002$), seedling height ($P = 0.001$), leaf production ($P < 0.001$), and rootshoot ratio ($P = 0.008$). In contrast, *Dipsacus fullonum* appeared resistant to allelopathic effects, with no significant differences in germination or growth relative to soil type ($P > 0.25$ for all measures). Our results support the role of allelopathy in the invasive success of *A. altissima* and further suggest that *A. altissima* may differentially affect resident native versus non-native species, potentially facilitating the spread of other non-natives in the invaded community.

Other published sources

Britton, N.L., and A. Brown. 1913. An illustrated flora of the northern United States, Canada and the British Possessions, Vol 2. Charles Scribner's Sons, New York. Vol. 2, pg. 446.

Miller, J.H. 2003. Nonnative invasive plants of southern forests: a field guide for identification and control. General Technical Report SRS–62. U.S. Department of Agriculture, Forest Service, Southern Research Station. 93 pp.

Summary: This book provides information on accurate identification and effective control of the 33 non-native plants, including *Ailanthus altissima,* and groups that are currently invading the forests of the 13 southern US states. It illustrates both growing and dormant season traits. It provides control strategies and selective herbicide application procedures.

Zheng, H., Y. Wu, J. Ding, D. Binion, W. Fu, and R. Reardon. 2004. Invasive Plants of Asian Origin Established in the United States and Their Natural Enemies -- Vol 1. United States Department of Agriculture, Forest Service. FHTET-2004-05. Morgantown, WV. 147 pp. wiki.bugwood.org/uploads/Ailanthus.pdf

Unpublished sources

Heisey, R.M. 2010. Allelopathic effects of *Ailanthus altissima* (tree-of-heaven) seeds and young seedlings. Oral poster at 95th Ecological Society of America Annual Meeting. Pittsburgh, Pennsylvania, August 1-6, 2010.

Author's summary: Recent investigations suggest allelopathy may be one factor that contributes to the invasive ability of *Ailanthus altissima*. Extracts of roots, bark, and leaves from *A. altissima* trees inhibit root growth of indicator species in laboratory bioassays. The major phytotoxin in *A. altissima* (ailanthone) exhibits strong herbicidal activity on many

weeds and crop species. Establishment of seedlings is critical for the invasion of new sites, yet little is known about the allelopathic effects of its seeds and young seedlings. This investigation evaluated the allelopathic potential of seeds and young seedlings of *A. altissima*. Allelopathic effects were quantified using aqueous extracts prepared from oven-dry *A. altissima* tissues and bioassays using garden cress (*Lepidium sativum*) seeds. Results: Extracts made from *A. altissima* seeds separated from the surrounding pericarp tissue (wing of the samara) were extremely phytotoxic. In contrast, extracts made with the surrounding pericarp tissue had very low toxicity. Investigations using soil in petri dishes indicate the phytotoxic compound is able to diffuse from the seeds into surrounding soil, where it inhibits radicle growth of other plant species. The allelopathic activity of 5-week-old, 14-week-old, and 1-year-old *A. altissima* seedlings was lower than that of seeds, but was comparable to that of mature trees. These results show that *A. altissima* seeds and young seedlings have strong allelopathic activity that is comparable to, or even greater than, that of mature trees

Hoshovsky, M.C. 1988. Element Stewardship Abstract for *Ailanthus altissima*, Tree-of-Heaven. The Nature Conservancy, Arlington, Virginia. 13 pp.

Annotation: This document provides a description of *Ailanthus altissima* and its ecology in undisturbed and disturbed habitats, plus a summary of management and monitoring methods.

Washington State Noxious Weed Control Board. 2011. Written Findings of the Washington State Noxious Weed Control Board, draft 29 August 2011.

Annotation: This document summarizes the botany, biology, and distribution of *Ailanthus altissima* (Mill.) Swingle and provides a comprehensive summary of control methods.

Databases, fact sheets, and websites

Connecticut Invasive Plant Working Group, University of Connecticut. Featured Invasive Plant: Tree-of-heaven (*Ailanthus altissima*). www.hort.uconn.edu/cipwg/invader_month/invader_of_the_month_Jan06_ailanthus.pdf

Fryer, J. 2010. Ailanthus altissima. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). www.fs.fed.us/database/feis/plants/tree/ailalt/introductory.html

Missouri Botanical Garden. *Ailanthus altissima*. www.missouribotanicalgarden.org/gardens-gardening/your-garden/plant-finder/plant-details/kc/a847/ailanthus-altissima.aspx

National Park Service, US Department of the Interior. Integrated Pest Management Manual: Exotic weeds II. www.nature.nps.gov/biology/ipm/manual/exweeds2.cfm

NatureServe Explorer. *Ailanthus altissima* (P. Mill.) Swingle. www.natureserve.org/explorer/servlet/NatureServe?searchName=Ailanthus%20altissima

Ontario Trees & Shrubs, Ailanthus (Ailanthus & Staghorn Sumac. Issue No. 148, January 2005. www.ontariotrees.com/main/species.php?id=2001

Plant Conservation Alliance's Alien Plant Working Group. Fact Sheet: Tree of Heaven, *Ailanthus altissima* (Mill.) Swingle. 5 pp. www.nps.gov/plants/alien/fact/pdf/aial1.pdf

Annotation: This fact sheet provides detailed information on various herbicide methods that will be of use to certified applicators who are managing Tree of Heaven.

United States Department of Agriculture, Forest Service. Forest Health Staff, Newtown Square, PA. Weed of the Week: Tree-of Heaven (*Ailanthus altissima*). www.na.fs.fed.us/fhp/invasive_plants/weeds/tree-of-heaven.pdf

United States Department of Agriculture, National Agriculture Library. National Invasive Species Information Center, Species Profiles: Tree-of-Heaven. www.invasivespeciesinfo.gov/plants/treeheaven.shtml

USDA-NRCS PLANTS Database *Ailanthus altissima* (Mill.) Swingle, tree of heaven. plants.usda.gov/java/profile?symbol=AIAL

Virginia Tech, Department of Forest Resources and Environmental Conservation. VTreeID: tree-of-Heaven, *Ailanthus altissima* (Mill.) Swingle. dendro.cnre.vt.edu/dendrology/syllabus/factsheet.cfm?ID=7

Washington State Noxious Weed Control Board. Tree-of-heaven, *Ailanthus altissima* www.nwcb.wa.gov/detail.asp?weed=174

Personal communications

Cronin, Elizabeth, Restoration Technician, Fort Rodd Hill National Park and National Historic Site, July 2011.

Hook, Fred, Parks Environmental Technician, City of Victoria. 9 February 2012.