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Biology, ecology, distribution and current status of *Heracleum mantegazzianum* Sommier & Levier

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ABSTRACT

Introduced from Europe for its unique appearance, Heracleum mantegazzianum Sommier & Levier (giant hogweed) is becoming increasingly prevalent across North America especially in the Northwestern and Northeastern States of the United States and Canada. Currently it is found along riverbanks, roadsides, waste places, and abundant lands. It is a member of the carrot family, Umbelliferae (Apiaceae). It is a biennial or a monocarpic short-lived perennial. It generally flowers in its third year of growth. It resembles different plant species during different stages of its life cycle and is often mistakenly planted as an ornamental due to the attractive flower heads it produces. Heracleum mantegazzianum is closely related to Heracleum lanatum Michx. (cow parsnip). It poses a threat to natural ecosystems and is also a weed in agricultural and urban areas. This species represents an increasing public health hazard. The plant exudes a clear watery sap which contains furanocoumarins. Contact with H. mantegazzianum can cause phytophotodermatitis, a serious skin inflammation caused by UV photo-activation, resulting in severe burns to the affected areas and severe blistering. Control measures must be taken in order to prevent its further infestations. The perennial nature of H. mantegazzianum and toxicity of the plant sap limits mechanical control options. Chemical control options include postemergence application of growth regulator herbicides, glyphosate or triclopyr, although limited information on its control is available. Ability to identify this weed and understand its biology will aid successful management efforts. Public education to dissuade gardeners from planting this attractive but noxious plant in their gardens is also necessary. This species should be watched carefully for its future infestation and subsequent spread as an invasive weed in agricultural and urban areas.

Keywords : *Heracleum mantegazzianum,* giant hogweed, HERMZ, furanocoumarins, invasive plant

The invasive species, *Heracleum mantegazzianum* Sommier & Levier (giant hogweed), is a member of the carrot family, Umbelliferae (Apiaceae). It is a biennial or a monocarpic short-lived perennial with tuberous root stalks which generate perennating buds each year. It colonizes a wide variety of habitats but is most common along roadsides, other rights-of-way, vacant lots, streams and rivers.

In the United States, *H. mantegazzianum* is currently listed as noxious weed under the Federal Noxious Weeds Act of 1974 whereby it must be reported and controlled when found and importation or interstate movement is illegal (Anon., 1999; USDA, 2012). It is listed as invasive in at least three state regulated lists (Oregon, Washington, and Pennsylvania) in the United States (Anon., 2005). In Canada, it is listed as noxious weed in Ontario, Vancouver Island and British Columbia (Page *et al*., 2006). In the United Kingdom, there is a ban on planting *Heracleum mantegazzianum* under the 1981 Wildlife and Countryside Act (Anon., 2005). This species is native to the natural range of the subalpine zone of the western Caucasus Mountains of Georgia, Azerbaijan, and southern Russia (Mandenova, 1951; Otte and Franke, 1998), and it was introduced as an ornamental plant to Europe, Canada and the United States. Because of its tenacious growth habit, the species escaped and became a weed species. Currently, it is found in Connecticut, District of Columbia, Indiana, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New York, Ohio, Oregon, Pennsylvania, Vermont, Washington, and Wisconsin (Anon., 2014). A comprehensive review on the biology of invasive alien species, *Heracleum mantegazzianum* was published in 2006 (Page *et al.,* 2006). The purpose of this review is to highlight the significance of the species as invasive plant and to summarize the current literature available on this species. This review may not be all-inclusive with available literature.

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Species name

Heracleum mantegazzianum (giant hogweed), Bayer Code: HERMZ, also referred commonly as giant bearclaw, wild parsnip, giant cow parsnip, and wild rhubarb, was described scientifically by Sommier and Levier in 1895. Its genus name is thought to be derived from Hercules, and the species is named after the Italian dermatologist Paulo Mantegazza (1831-1910) (Ochsmann, 1996). Earlier authors referred to this plant with other species names as *stevenii*, *antasiaticum*, *gigantium*, and *villosum*. The genus *Heracleum* encompasses about 70 species which are found mostly in north temperate regions, particularly central Asia (Mandenova, 1951).

Description and account of variation

Heracleum mantegazzianum is considered to be the largest herbaceous plant in European flora (Pysek, 1994). Its competitive nature has been attributed to its rapid and prolific growth. Most sources have documented giant hogweed as a biennial or perennial monocarpic herb (Ochsmann, 1996; Bhowmik *et al*., 2003). The illustrations (Fig. 1A – 1F) show compound leaf, inflorescence, umbel, individual flower, fruit and mericarp. The genus *Heracleum* is characterized by tall stout stems with soft, flexible roots that contain large amounts of starch (Ochsmann, 1996; Shunova, 1972). The root of giant hogweed is pale yellow or brown, and exudes a yellow sap from the cut surface.

The cotyledons of the seedling are abruptly contracted into a petiole (Tiley *et al*., 1996). The cotyledons are fiddle shaped, and elevated by the petioles. Cotyledons of germinating seedlings emerge under field conditions and may persist for several weeks before the first foliage leaf emerge. The first true leaves are simple, rounded and more or less kidney-shaped with a serated margin (Fig. 2A). The leaves are alternate. Lower leaves are long and compound, divided into three to five pinnate segments (Fig. 2B).

Plants growing on shallow soil do not possess true taproots but are adapted to adverse conditions by developing a highly branched, laterally spreading root system, which provides good anchor and enough food reserves for growth (Caffrey, 1999). The taproot is initially deep, narrow, and gets thicker as it starts to accumulate food reserves and may divide as the plant matures. The largest root branches grow more-or-less vertically with finer horizontal branches reaching to the upper layer of soil (Tiley *et al*., 1996). The root crown reaches up to 15 cm in diameter at flowering after which it becomes lignified. *Heracleum mantegazzianum* stems may reach a diameter of 10 cm at the base, and up to 500 cm in height. Older plants have a solid stem with old leaf scars between the root and the stem base. Otherwise, the stem is hollow (Fig. 3A) and ridged on the external surface with distinct purple blotches that become increasingly less conspicuous near the top. Stem and petioles are covered with postulate bristles (Fig. 3B). Scars of abscised leaves remain on the stem. In the dormant over-wintering state, this species bears a single large terminal bud covered by rudimentary bases of small leaves (Roche, 1992; Tiley *et al*., 1996).

Most members of the genus *Heracleum* possess compound leaves with leaflets in multiples of three arranged alternately along a common axis. The leaf blades of *Heracleum mantegazzianum* are divided into three or more deeply lobed parts (Fig. 1A). Ochsmann (1996) observed a seasonal dimorphism in the leaf blades where the blade segments of leaves formed in spring were much broader with higher surface area than those formed in summer months, which had narrow and longer segments. The petiole is stout, fleshy, hollow, hairy, and has short leaf sheaths at the base. Lower leaves have an inflated sheath petiole and the upper leaves get progressively smaller and sessile, and become bracteate higher up the stem. During the vegetative phase, the rosettes have three to four leaves with older leaves dying off in equal numbers as new leaves are continually formed. Flowering plants have on average three to four stem-leaves with a developed petiole, while rarely more than one or two basal leaves remain. The rachis of the lower leaves of *Heracleum mantegazzianum* reaches a length of about 60 to 140 cm and has a diameter of up to 4 cm (Ochsmann, 1996).

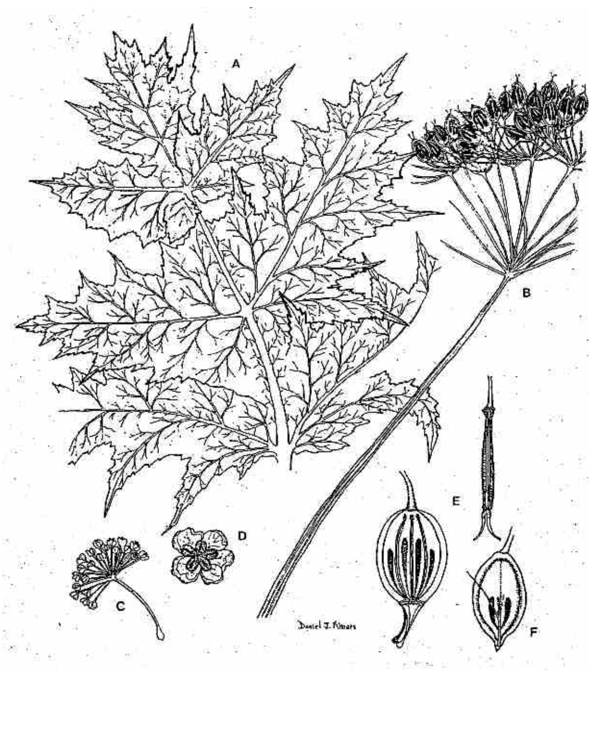

Fig. 1 : *Heracleum mantegazzianum* Somm. & Lev. A. portion of leaf, showing its large and compound nature; B. portion of inflorescence; C. portion of umbel; D. individual staminate flower from lateral inflorescence; E. fruit; F. mericarp, following dehiscence.

Fig. 2A: *Heracleum mantegazzianum* seedlings. (http://weedscanada.ca/parsely.html)

Fig. 2B: Young seedling growth of *H. mantegazzianum* (http://www.massnrc.org/pests/pestFAQsheets/hogweed.html

Fig. 3A: Ridges and coarse hairs on hollow stem of *H. mantegazzianum*. (Pennsylvania Dept. of Agriculture)

Fig. 3B: Stem of *H. mantegazzianum* plant with reddish marks. (Massachusetts Department of Agricultural Resources)

Fig. 4A: Umbel inflorescence of *H. mantegazzianum*

Fig. 4B: Fruit of *H. mantegazzianum* with oil ducts. (USDA APHIS PPQ Archives, USDA APHIS PPQ)

Fig. 5A: *H. mantegazzianum* can reach 3 to 4.5 m in height. (Massachusetts Department of Agricultural Resources)

Fig. 5B: Stand of *H. mantegazzianum*. (USDA APHIS PPQ Archives)

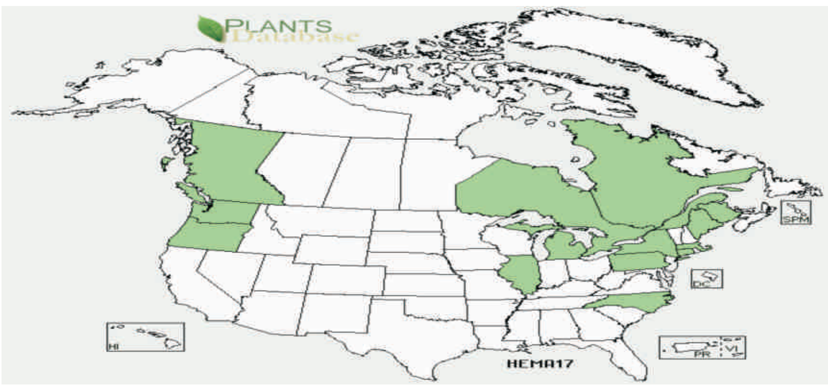

Fig. 6 : Distribution of *H. mantegazzianum* in North America. USDA, 2015; NRCS-Plant Data Base (as of July 29, 2014).

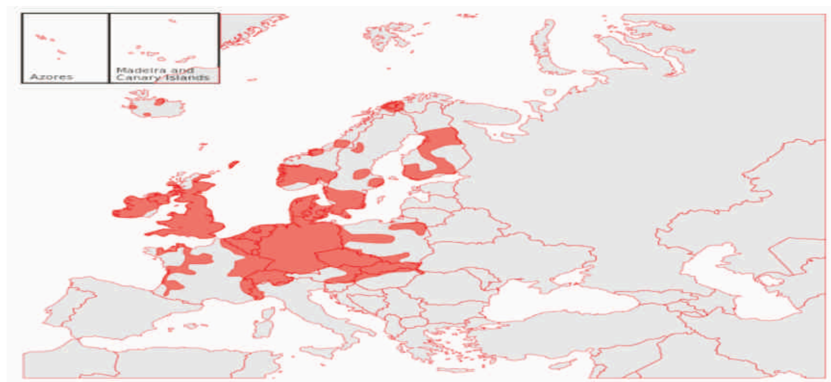

Fig. 7: Distribution of *H. mantegazzianum* in Europe (2005). (http://wikipedia.org/wiki/Heracleum_mantegazzianum)

Heracleum mantegazzianum has different types of unicellular hairs (trichomes). Hairs of the stem and umbel rays are more conspicuous than leaf hairs. The stem hairs, tapering to a point, are as long as 1 mm and carry a head-shaped swelling and a little pinnacle at the upper end (Ochsmann, 1996). Hairs on the underside of the leaf are dense, fine, and about 0.25 mm long. Hairs on ripe fruits die off during fruit development. Short acute triangular hairs are also found dispersed over the inflorescence (Ochsmann, 1996).

The trichomes on the leaf epidermis of giant hogweed are surrounded by six to eight crown cells. The epidermal cells are striated with moderately thick anticlinal walls. There are distinct striations at the base of each trichome which are fragmented to form projections over the remaining length of trichome (Arora *et al*., 1982).

Heracleum mantegazzianum leaves have three morphologically different kinds of stomatal apparatus (Arora *et al*., 1982):

(a) Anomocytic – guard cells surrounded by more than three cells which are indistinguishable in dimensions, shape, or form from the other epidermal cells.

(b) Anisocytic – guard cells surrounded by three well-defined subsidiary cells of which one is smaller than the other two. These kinds of stomata are more common in giant hogweed.

(c) Tetracytic – guard cells surrounded by four subsidiary cells, two lateral and two polar.

The inflorescence of *Heracleum mantegazzianum* forms compound umbels up to 80 cm in diameter with 50-150 unequal hairy rays. Rays are shorter and thicker at the center of the umbel and get longer at the edge bringing secondary umbels to a similar sub spherical plane. On a short hollow peduncle there are compound umbels, which are subtended by bracts (Tiley *et al*., 1996). The terminal umbel is largest and hermaphrodite, surrounded by up to eight satellite umbels on elongated curving stalks raising them up to 40 cm above the level of terminal umbel. The satellite umbels may degenerate and become sterile under stress. Umbels mature in sequence; the lower umbels are smaller and sometimes male. Length of the flower's stalk in an inflorescence decreases from the periphery of the primary umbel inwards. The floral surface of compound umbel is hemispherical. Stem diameter at the base of the inflorescence, total numbers, sizes and weights of satellite and terminal umbels per plant decreases with increasing population density (Tiley *et al*., 1996). In heavily shaded plants, large-sized terminal umbels reduce the satellite umbels which tend to be infertile resulting in the reduction of size and number of fruitlets (Tiley and Philp, 1997).

Heracleum mantegazzianum always has a developed bract below the inflorescence (Fig. 4A). The bract is about 1 cm long and consists of about 10 leaves. They are usually folded back but can also stick out noticeably (Ochsmann, 1996). Bracts below the inflorescence are usually several, linear or ovate and tapering to a point. The bracteole is linear and soon drops off.

The flowers are white or occasionally pinkish. Sepals are triangular, petals up to 12 mm with radiating outer petals (Tiley *et al*., 1996). Styles have an enlarged base. The anther splits open at maturity and pollen is shed before the stigma becomes receptive (Tiley *et al*., 1996). Petals are pure white and are hairy on the outer side. The anthers are dark olive green or purple in color. The blossoms of *Heracleum mantegazzianum* have relatively strong, unpleasant urine-like smell (Ochsmann, 1996). The diameter of sterile pollen (triploid) is generally 1 to 3 mm less than that of fertile pollen.

Fruits are elliptical, 6 to 18 mm long, and 4 to 10 mm wide. Fruits usually lack hairs or have small projections on the epidermis and are dorsally compressed. Fruits split into two-winged one-seeded mericarps, which break apart at maturity. The mericarps have three to five conspicuous solitary oil ducts on the outer side (Tiley *et al*., 1996). Oil ducts reach about three-fourths the length of a fruit and are strongly clubbed at the bottom (Fig. 4B). The oil ducts contain oil that is aromatic and almost colorless. The endosperm is oily, and mature fruits have strong resinous smell (Tiley *et al*., 1996). A single plant can produce up to 100,000 viable seeds or 20,000 seeds on an average (Otte and Franke, 1998).

Wanscher (1932) counted n = 11 from material in cultivation at Copenhagen, and Hindakova and Schwarzova (1987) counted 2n = 22 from material naturalized in Slovakia. The only count from plants growing in their native range in Georgia was 2n = 22 (Gagnidze and Chkheidze, 1975). Another gametophyte count of n = 11 was reported from plants cultivated at Portland, Oregon (Bell and Constance, 1966). In Canada, chromosome counts of n = 11 and 2n = 22 were obtained from *H. mantegazzianum* plants that were grown from seeds collected at Wakefield, Quebec (Page *et al*., 2006).

Little intra-specific variation has been noted in *Heracleum mantegazzianum*. However, Walker *et al*.

(2003) used microsatellite DNA markers to assess genetic diversity in 13 *H. mantegazzianum* populations in three drainage catchments in Britain. They found that overall genetic variation was high, and that populations from the same catchment were more similar, suggesting connections through waterborne dispersal.

Species resembling *Heracleum mantegazzianum*

Identification of *Heracleum mantegazzianum* plant is vital in understanding ecological consequences in various environments. *Heracleum mantegazzianum* closely resembles the *Heracleum lanatum* Michx. or *Heracleum maximum* Bartram (cow parsnip), a plant native to the maritime Pacific Northwest, which has a similar leaf and flower. However, there are few major differences between the two. *Heracleum lanatum* plants grow 120 to 150 cm tall, while *H. mantegazzianum* plants can grow as high as 500 cm. While *H. lanatum* can have minor purplish spots on stem, *H. mantegazzianum* has prominent dark purple specks on the central stem (Booy *et al*.[2]). Also, *H. lanatum* hairs are wavy/downy and longer, while those of *H. mantegazzianum* are spiky, stiff, and shorter. Flower heads of *H. mantegazzianum* can reach up to 80 cm in diameter, while that of *H. Maximum* seldom exceeds 30 cm (Robson[3]).

Habitat

In its native habitat, *Heracleum mantegazzianum* occurs in forest edges and glades, often in stream sides in mountain areas with rainfall between 1000 and 2000 mm. It tolerates permanently moist soil, water-logging and winter flooding associated with riverside habitat. However, once established *Heracleum mantegazzianum* can thrive well on drier and drained sites. Establishment of *Heracleum mantegazzianum* on highly acid soil pH is unlikely (Tiley *et al*., 1996). Invasion of this species in different habitats has been reported by Pysek and Pysek (1995). In warmer climates, it is favored by semi-shaded habitats. This species can also invade close communities such as grassland (Tiley *et al*., 1996). *Heracleum mantegazzianum* establishes itself in moist herbaceous communities with good nutrient levels, in lowland to sub-montane zones (Otte and Franke, 1998).

In the United Kingdom, *Heracleum mantegazzianum* is seen mostly in sandy and silty soil along riverbanks, canals, lakeshores and/or damp waste ground and other damp habitats (Jackson, 1989). Because it often grows in wet areas, it is considered to an invasive riverbank weed. Its establishment is possible in a range of habitats and substrates, provided there is sufficient moisture at the seeding stage (Tiley *et al*., 1996). In contrast, under conditions in Germany, giant hogweed grows frequently on (very) dry road verges and even in gaps between paving stones, where the plants remain small. It occurs in dry locations only with a few, very small sized plants, while in water-logged sites plants die early due to root damage (Ochsmann, 1996). Clegg and Grace (1974) reported that high potassium and calcium levels are especially favorable for invasion of *H. mantegazzianum*.

Heracleum mantegazzianum has successfully established itself where other alien plants have failed which may be due to the following reasons (Caffrey, 1999): (a) the paucity of natural pests and diseases, which could limit its spread; (b) adaptation to local conditions through natural selection; (c) ability to grow in disturbed areas; and (d) prolific nature of the plant.

The species frequently occurs in habitats, which require transport of seeds by wind, water or human activities. Seeds landing in water can float for about three days before becoming waterlogged and can travel long distances, particularly during floods[4].

Geographical distribution

Heracleum mantegazzianum is native to the Caucasus Mountains, a region of Asia that lies between the Black and Caspian seas, where it occurs in the forest belt and the southern meadow slopes. The natural range of *H. mantegazzianum* is the subalpine zone of the western Caucasus Mountains of Georgia, Azerbaijan, and southern Russia (Mandenova, 1951; Otte and Franke, 1998), where it is found in meadows, clearings, and forest edges between 1500 and 1850 m. Since the 19th Century, *H. mantegazzianu*m and a number of other Caucasus plants have been introduced to a variety of regions of both the northern and southern hemispheres, particularly Europe (Clegg and Grace, 1974; Knapp and Hacker, 1984; Pysek, 1991).

Other species of the genus *Heracleum* grow in the eastern and southern Caucasus as well as the mountains of northeast Turkey (Pontic Mountains) and northern Iran (Elburz Mountains) (Ochsmann, 1996). In the early twentieth century, it was planted out of curiosity in arboreta and gardens in Europe and North America. It soon escaped and started to grow in surrounding areas, especially riparian and urban sites.

In the United States, *Heracleum mantegazzianu*m has been reported in the states of Connecticut, District of Columbia, Indiana, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New York, Ohio, Oregon, Pennsylvania, Vermont, Washington, and Wisconsin (Roche, 1992; Anon., 2014; USDA, 2015) (Fig. 6). In Massachusetts, *H. mantegazzianum* was found in 19 sites in seven counties in Massachusetts including Andover, Blandford, Boston, Easthampton, Granville, Groton, Huntington, Southwick, Sutton, Turners Falls, Wakefield, Westfield, and West Springfield (Bhowmik *et al*., 2003; Anon., 2015). Survey conducted by West Virginia State Department of Agriculture in 2003 indicated that *Heracleum mantegazzianum* is not present in West Virginia (Chandran and Bhowmik, 2004).

Nine counties have reported of *Heracleum mantegazzianum* in Washington State (Anon., 2014). Single populations occur near Potlatch, Mason County; in Vancouver, Clark County; in Coupeville, Island County; and at Marysville, Snohomish County. Population that is more widespread exists in King, Pierce, Skagit, Thurston and Whatcom counties. Numerous infestations have found to occur in and near Olympia, which include Rainier and Capital Lake. *Heracleum mantegazzianum* in the Seattle area grows along lake Washington Boulevard, and Rainier Avenue south near Renton and in West Seattle and the Wallingford area (Roche, 1992). It is found throughout in Bellevue, Auburn, Bothell, Burien, Federal Way, Des Moines, Issaquah, Kent, Kirkland, Redmond, Lake Forest Park, Newcastle, Renton, Normandy Park, SeaTac, Shoreline, Tukwila, Vashon, Woodinville and few more rural areas of the county. Most infestations are on the urban residential areas and in city parks, open space areas, schools and churches, vacant lots, roadsides, railroads, ravines and along streams and rivers.

In Canada, it is found from British Columbia to Newfoundland (Page *et al*., 2006). The center of its present distribution in Canada is the Bruce peninsula southwards to Perth County and Waterloo region (Fig. 6). It has spread as far as Haliburton County and north to the tip of the Bruce Peninsula at Tobermory (Morton, 1978).

In Europe, there is a continuing increase in its distribution in Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Holland, Hungary, Iceland, Ireland, Italy, Liechtenstein, Norway, Slovakia, Sweden, Switzerland and United Kingdom (Tutin *et al*., 1968; Hindakova and Schwarzova, 1987; Tiley *et al*., 1996; Jahodova *et al*., 2007) (Fig. 7). It has spread throughout the British Isles, extending from the south coast of England to Shetland in the north of Scotland. It has been recorded in 119 out of the 153 vice counties of the British Isles, being distributed mainly in the southeastern England and southwest and eastern Scotland. In the British Isles, it is mainly a lowland species and has been recorded from sea level up to an altitude of 213 m on the river Don, Aberdeenshire and at 170 m in western Scotland (Tiley *et al*., 1996; Otte *et al*., 2007).

In Czechoslovakia, it occurs extensively in the North, which may reflect that these species prefer cooler, more humid areas than the warmer regions. *Heracleum mantegazzianum* occurs in Czech Republic over a wide range of altitude (Pysek, 1991; Pysek *et al*., 2012). In Sweden, it occurs throughout the country. It appears to be spreading rapidly in south Norway and occurs on all types of soil in Denmark, including the sandy soils in western Jutland (Tiley *et al*., 1996). The distribution of the species can be predicted as reported by Nielsen *et al*., 2008.

Growth and development

In native habitats the first signs of growth of *Heracleum mantegazzianum*, in its vegetative phase, are visible in late December by greening and swelling of the crown buds. This is followed by a gradual development of small leaf blades without petioles and with narrow leaf segments. These give rise to more petiolated leaves in February and March. In late April and early May signs of stem and inflorescence development become visible within the growing apex of the shoot emerging from the bases of the petioles (Ochsmann, 1996; Shumova, 1972). As temperatures rise there is a period of rapid extension growth. A dense leaf canopy develops with a mean stand height of around 80 cm. By early June a swollen terminal bud sheathed in bracts is visible, from which the first and largest compound umbel emerges. This is followed by the satellite umbels arising from the base of the terminal umbel peduncle (Tiley *et al*., 1996). The final phase comprises of the reproductive growth. Small true leaves appear at the shoot nodes, while the basal leaves of the rosette senesces (Otte and Franke, 1998). The phenology of *Heracleum mantegazzianum* under different conditions in the U.S. is yet to be documented. Normally, the primary umbels of *H. mantegazzianum* have protandrous, (anthers mature before carpels) hermaphrodite blossoms so that a male and a female phase can be distinguished. In contrast, the secondary umbels exhibit functional male blossoms in varying degrees, the proportion of which increases in peripheral umbels. The male phase of the hermaphrodite-blossoms lasts for about 4 to 9 days, the female phase lasts longer with a duration of 5 to 16 days. In *Heracleum mantegazzianum* male and female blossom phases normally coincide due to the umbels' size. While the outer blossoms of the umbel are in the female phase, the blossoms in the center are in the male phase so neighbor-pollination (geitonogamy) is fostered among the umbels (Ochsmann, 1996).

Flowers in an umbel open sequentially from the periphery inwards (Fig. 4A). Rays and other parts of the inflorescence enlarge continuously. Flowering plants, which are damaged or cut above the root, may survive for one or more seasons (Tiley *et al*., 1996). Caffrey (1994) recorded that the peripheral rays on the highest order umbels produce the largest and best quality seeds. Apical dominance ensures that the main reproductive effort of the plant is concentrated into the terminal and satellite umbels and this limits the development and setting of later flowering and lower order umbels. Each flower produces two one seeded fruits thus giving a potential seed production of over 100,000 per plant (Pysek, 1991). Maturation of fruits occurs from periphery to centre in the compound umbel (Tiley *et al*., 1996). In native habitats, the fruit ripens between the end of June and beginning of July, while majority of the fruits ripen in the first half of the July. Individual plants, on an average, produce about 20,000 mericarps (Ochsmann, 1996).

The majority of plants die back in late August (Caffrey, 1999). A plant flowers and bears fruits only once before senescing. Senescence is caused by the depletion of nutrient and energy reserves (Otte and Franke, 1998).

Reproduction

Heracleum mantegazzianum is vegetative during its first year of growth. It reproduces through seeds, perennating buds formed on the crown, and tuberous root stocks (Tiley *et al*., 1996). Perennating buds are formed at ground level. The aerial shoots may die at the onset of unfavorable conditions. Stewart and Grace (1984) showed that plants usually flower in their third year, but may also flower in second, fourth or fifth year. Either crown or root stocks can regenerate new shoots which may bear flower heads. The flowering stems may be weak if the plant is damaged prior to flowering.

***H*ybridization of *Heracleum s*pecies**

Hybridization is unusual between species in the family Apiaceae, but occasional hybrids between *H. mantegazzianum* and *H. sphondylium* have been reported in Europe where both species grow in proximity (Weimarck *et al*., 1979; Tutin, 1980; Grace and Stewart, 1982; Stewart and Grace, 1984; Ochsmann, 1996). Fertility of hybrids is low (seed set less than or equal to 1%; pollen stainability less than or equal to 7%) and introgression has not been detected (Weimarck *et al*., 1979; Stewart and Grace, 1984). Experimental crosses of *H. mantegazzianum* and *H. sphondylium* in Scotland have been successful only when the pistillate parent was *H. sphondylium* (Steward and Grace, 1984). The presence of *H. sphondylium* × *H. mantegazzianum* hybrids in the field, the ease of artificial hybridization, and the absence of specialized pollination mechanisms suggests that *H. mantegazzianum* may hybridize with the North American *H. maximum,* which is part of the circumboreal *H. sphondylium* species complex. However, no hybrids have been reported in Canada (Page *et al*., 2006).

Ecological implications

Heracleum mantegazzianum is a large plant, which can shade out the natural flora and can make the ground vegetation of riverbanks thin leading to the risk of erosion in winter (Bhowmik *et al.,* 2003). The plant is aesthetically attractive but there are a number of disadvantages, which make it undesirable. Dense growth can restrict access in amenity areas and large plants on roadsides can obstruct visibility (Tiley and Philip, 1997). Dense growth of this plant may also suppress and exclude indigenous herbaceous plant species, which play an important role in the riverbank stabilization. This results in erosion during winter floods, with large amount of soil being washed into the river (Caffrey, 1999).

All parts of the spring plant are resistance to frost, including over-wintering roots, newly germinated seedlings, rosette buds and young leaf growth in spring. Over-wintering roots and sprouting shoots have survived air temperatures as low as -17 C in Scotland (Tiley *et al*., 1996). Leaf senescence can be hastened by low temperatures in early autumn (Shumova, 1972). In prolonged dry summer spells, the leaf blades can become flaccid and the whole plant may be reduced in size. Plants are shorter and smaller where rooting is restricted. The branched taproot is tolerant of poorly drained or marshy areas. Vegetative as well as flowering plants withstand and recover from temporary riverbank flooding in summer. The much-divided leaves are moderately resistant to wind but unseasonal gales can cause laceration of larger leaves and snapping of petioles. On exposed sites, leaf tips and edges become brown. Wind is a primary means of seed dispersal in autumn (Tiley *et al*., 1996; Pergl *et al*., 2011). Pergl *et al*., 2012 reported that low persistence of a monocarpic invasive plant in historical sites biases our perception of its actual distribution.

The establishment and rapid spread of *H. mantegazzianum* depends on dispersal of seeds both locally and regionally from founder populations. Original populations (first introduced) are generally very small, often a single plant in garden cultivation, and initial population increases are slowed by the requirement for 2 to 5 yr of growth before flowering and seed production occur. As Otte and Franke (1998) documented, seed dispersal in the absence of water, wind, or soil movement is poor. However, once the population has expanded into riparian areas, regional population increase can occur rapidly through waterborne dispersal (Pysek, 1994; Wadsworth *et al*., 2000; Pysek *et al*., 2007).

Pysek (1994) and Pysek and Pysek (1995) reconstructed the spread of *H. mantegazzianum* in the Czech Republic. They documented an 80-yr lag phase between initial establishment and the onset of an exponential growth phase. During the lag phase, its spread was associated with its cultivation as a garden ornamental and subsequently along watercourses and other dispersal routes (Pysek, 1994). During the exponential phase (post-1945), populations developed away from dispersal-related habitats and populations became common throughout the general landscape. Population growth in the British Isles has followed a similar pattern (Tiley *et al*., 1996; Collingham *et al*., 2000). Wadsworth *et al.* (2000) modelled the rate of spread of *H. mantegazzianum* in a single watershed and found there was a lag phase of 10 to 25 yr before exponential growth in occupancy of suitable habitats occurred.

Seed production and dispersal

The large inflorescence of *H. mantegazzianum* produces prodigious amounts of seed. In central Europe, each of the several large umbels may produce 5,000 to 6,500 seeds (Pysek, 1991; Otte and Franke, 1998). Recently, Bowers *et al*. (2011) reported that one single *H. mantegazzianum* plant can produce more than 10,000 viable seeds in Pennsylvania, United States. In the Czech Republic, Pysek and Pysek (1995) found that up to 107,000 seeds may be produced by a single plant. Tiley and Philp (1994) estimated 60,000 flowers (producing up to 120,000 seeds) on one large plant examined in Scotland. Plants from Scotland studied showed a seed set of 84% and pollen stainability (cotton blue) of 91% (Weimarck *et al*., 1979). Stewart and Grace (1984) found that mean seed set was minimal when flowers within a single umbel were used (1%), but 68% when flowers between different umbels on the same plant were used. Mean seed set in flowers between different cross-pollinated plants was 64% (range 47 to 85%). Germination after 22 wk at 2°C stratification was less for seed from self-pollinated than cross-pollinated flowers, 27% versus 59%, respectively. The fruit splits into two flat and winged mericarps each up to 20 mg in weight and possessing distinctive oil tubes (Fig. 4B). The light, buoyant fruit may be waterborne for long distances and also carried short distances by strong air currents (Tiley *et al*., 1996).The arrangement of ripe mericarps on the carpophore (part of flower axis to which carpel is attached) helps them to overlap with umbels on neighboring mericarps. The pointed prickles of mericarps make this connection, due to which dry carpophores are stretched like feathers. By wind movement or by animal contact the mericarps break off at the point of attachment on the carpophores and are released abruptly from the umbel. This mechanism helps the mericarps to scatter 2 to 3 m even in calm wind. The mericarps rotate during their "flight" non-uniformly about their longitudinal axis so that the velocity of their fall is greatly reduced. Distances of up to 100 m can be covered because of the large surface and low weight (Ochsmann, 1996; Moravcova *et al*., 2007; Pergl *et al*., 2011).

Dispersal can be through following mechanisms by: a) water: seeds and fragments are carried downstream, b) vegetation management of watercourse banks: routine maintenance of bank side vegetation by hand and machinery has a potential to spread seed, c) transfer of material and associated actions: by vehicles, especially their wheels when traveling between on and off road sites; by movement of agricultural machinery from field's edges to mid fields sites; by seeds during mowing, plowing *etc.,* d) movement of animals especially through cattle, e) recreational activities such as golfing, trolleys and vehicles wheels around sites and between sites, f) clearance for site management or development; on-site spoil movements. g) natural dispersal by the plants includes aerial projection of seeds and wind dispersal, h) seeds of giant hogweed can be thrown for 5 m when enhanced by air turbulence (Dawson and Holland, 1999).

Seed germination, seed bank and seed viability

In a seed bank study at seven sites in the Czech Republic, Krinke *et al*. (2005) found that the numbers of seeds in the seed bank was directly related to plant density and that the numbers and proportion of viable seeds at any one site varied between years. Pooled results showed a mean total soil seed population of 2,600 to 10,838 m^{-2} in autumn, 2,696 to 7185 m^{-2} in spring and 265 to 2,337 m^{-2} in summer, 95% of which were present in the upper 5 cm soil. However, the population of viable seeds varied from 853 to 6,665 in autumn, 846 to 3,242 in spring and 27 to 388 in summer. Seeds may persist in the soil for 5 to 6 yr before germinating (Andersen, 1994) and can remain viable in the soil for up to 15 yr (Andersen and Calov, 1996). However, Otte and Franke (1998) found that seed-banks were minimal for populations in Germany. Morton

(1978) found that seeds from Ontario plants stored at room temperature were still viable after 7 yr, although Lundstrom (1990) stated that seeds may remain viable for as much as 15 yr.

In the Czech Republic, Moravcova *et al.* (2005) found the mean germination rate of greater than 90% under optimal conditions in laboratory studies. Seedling mortality is also high. In Ireland, germination begins in February and peaks in April. Only 1.2% and 13.7% of seedlings present in April were extant by the end of August in the two populations studied by Caffrey (1999). Tiley *et al.,* (1996) estimated that less than 23% of germinated seedlings survived to maturity. No study of mortality factors was reviewed but since most of the 20,000 to 100,000 seeds produced per plant fall within a few metres of the parent plant (Otte and Franke, 1998), seedlings develop under very crowded conditions and mortality is expected to be high.

Seedling survival

Seedling survival is dependent upon environmental conditions. From several thousands of germinating seedlings from a single plant, only a few individuals that have accumulated sufficient nutrient reserves in the roots may survive (Otte and Franke, 1998). The nutrient reserves enable the plant to develop a new vegetative body during initial growth period. During emergence of the seedling, the hypocotyl is brought above the soil up to 10 cm by vertical contraction of the central tap-root, which helps in rapid sprouting. Subsequently, leaf growth progresses exponentially, making the plant more competitive. After an initial slow growth in the spring, stem elongation, especially in the final flowering year, proceeds at an exponential rate (Tiley *et al*., 1996). During the vegetative growth phase, regenerative growth can occur because the plant is able to draw on nutrients from in the root reserves (Otte and Franke, 1998).

Economic and environmental impacts

Heracleum mantegazzianumm species is considered to be one of the most noxious invading plants in Europe (Pysek *et al*., 1998). It poses a threat to natural ecosystems and human health, as well as being a weed in agricultural and urbanized areas. In Europe, it has rapidly established in a variety of semi-natural and man-made ecosystems, particularly floodplains, riparian zones, forest edges, roadsides, meadows, open forest, and unmanaged urban areas (Williamson and Forbes, 1982; Tiley and Philp, 1992; Pysek, 1994; Pysek and Prach, 1994; Otte and Franke, 1998). It often forms monospecific stands (Fig. 5A, 5B) where its tall stems and large leaves effectively compete for light against other plants (Clegg and Grace, 1974; Williamson and Forbes, 1982; Pysek, 1991; Andersen, 1994; Otte and Franke, 1998).

This species is especially invasive in riparian ecosystems, where new colonies can be established from waterborne seeds (Dawe and White, 1979; Pysek, 1994). It can displace riparian vegetation and increase stream bank erosion during the winter when *H. mantegazzianum* is senescent (Wright, 1984; Tiley and Philp, 1992, 1994; Dodd *et al*., 1994). Instability of river banks dominated by *H. mantegazzianum* in Great Britain and Ireland poses a serious threat to salmon spawning habitats (Caffrey, 1999). Invasion of this species has been reported by Pysek *et al*., (2008), Hejda *et al*., (2009), Dostal *et al.,* (2013), Moenickers and Thiele (2013) and Jandova *et al*., (2014). Recently, the long-term impact of *H. mantegazzianum* on soil chemical and biological characteristics of soil has been reported by Jandova *et al*. (2014).

Allelopathic effects and invasion

There is some evidence of allelopathy in *Heracleum* species (Junttila, 1975, 1976), which may increase the detrimental impact of *H. mantegazzianum* on other plants. However, Wille *et al*., (2013) reported limited allelopathic effects of *H. mantegazzianum* on germination of native herbs. In general, *H. mantegazzianum* is believed to reduce diversity of native plant communities (Tiley and Philp, 1992; Godefroid, 1998), although there is little comprehensive research to assess this impact. A study in Hungary suggested that acetone extracts of *H. mantegazzianum* could have useful allelopathic effects on other weeds (Solymosi, 1994).

Concerns to human health

Heracleum mantegazzianum represents an increasing public health hazard. The major phytotoxic principles in *Heracleum* species are linear furanocoumarins or psoralens, mainly 5-methoxypsoralen and 8-methoxypsoralen (Pathak *et al.,* 1967; Nielsen, 1970; Molho *et al*., 1971; Pira *et al*., 1989).

The sap of *H. mantegazzianum* causes severe blistering of human skin upon exposure to sunlight, a condition referred to as phytophotodermatitis. The term, introduced by Klaber (1942), has been defined by Bellringer (1949) as a bullous eruption appearing on parts of the body that have been in contact with plants and exposed to the sun simultaneously. It may take up to 48 hours for symptoms to manifest after initial contact and exposure to sunlight. This condition has been more widely reported by gardeners exposed inadvertently to *Heracleum mantegazzianum* sap. Initial erythematous and bullous reaction occurs only in the areas of body which are exposed to sunlight. Hyperpigmentation follows 1 to 2 wk after UV light exposure and it may last months to years (Thomas and Theodore, 2000). The damage may not be immediately apparent however, because the blisters occur when the skin is damp or wet or is exposed to sunlight or some other source of UV light. About 50% of the plants, which cause phytophotodermatitis, belong to the family Umbelliferae (Drever and Hunter, 1970). For phytophotodermatitis to occur, the skin must come into contact with: (a) a compound called furanocoumarin, a substance that occur naturally in the leaves, roots and fruits of the *Heracleum mantegazzianum* (plants in the Umbelliferae family also contain this) (b) ultra violet radiations of more than 3,200 A^0. It can be concluded that all individuals exposed in this way are liable to be affected, as photosensitization is involved and not an allergic mechanism (Jones and Russell, 1968). Pira *et al*., (1989) in Italy and Knudsen (1983) in Denmark found that the highest contents of phototoxic substances are in leaves, and lowest in stems and petioles, with the roots having intermediate contents. *Heracleum mantegazzianum* contains 5-methoxypsoralen and 8-methoxysoralen and acts as one of the main cause of phytophotodermatitis in U. K and the United States (Thomas and Theodore, 2000). Drever and Hunter (1970) described cases of phytophotodermatitis in children and adults from Scotland. Symptoms appeared 24 to 48 hours after contact and involved mild to severe erythematous reaction with or without vesicles or bullae, mostly on the exposed parts of the body.

The bristly hairs on *H. mantegazzianum* contain furanocoumarins and any contact of skin with the plant can result in phyto-photodermatitis (Dennes *et al*., 2013; Mehta and Statham, 2007). Furanocoumarin induced dermatitis typically consists of painful blisters that form within 48 h and become pigmented scars that can last as long as 6 yr, but more typically disappear after several months (Sommer and Jillson, 1967; Morton, 1978; Tiley *et al*.,1996). Symptoms range from painful watery blisters, well illustrated by Nielsen *et al.* (2005), to full chemical burn (Chan *et al*., 2011). This occurs within 1 to 3 days on exposure to sunlight (Jakubska-Busse *et al*., 2013). Under cloudy conditions there may be no reaction. It may occasionally cause a recurrent dermatitis which can become a serious handicap (Williamson and Forbes, 1982; Klimaszyk *et al*., 2014). The compounds contained in seed essential oils may pose a risk to the eyes, skin and respiratory system (Jakubska-Busse *et al*., 2013). Large doses of furanocoumarins can cause cancer or fetus malformation (Nielsen et al., 2005). Immediately after exposure, the skin should be washed with soap and cold water to remove plant sap, and protected from sunlight until at least 48 hours post-exposure even if asymptomatic. Severe cases possibly require hospitalisation (Derraik, 2007). The health hazards of this species are one of the main reasons for concern over its spread. In tests on bacteria, Clarke (1975) showed that the sap of *H. mantegazzianum* could be mutagenic.

Potential uses

Heracleum mantegazzianum has been widely grown as an ornamental in Europe, thanks to its striking appearance and usefulness in flower arranging. It is still available via the Internet from commercial nurseries in Europe and North America. Buttenschøn and Nielsen (2007) commented that *H. mantegazzianum* has been widely grown as a forage plant in Eastern Europe in the past. In invasive stands, fresh weights of up to 188,000 kg ha^{-1} have been measured and dry weights of 12,000 to 14,000 kg ha^{-1} above ground and 4,800 kg ha^{-1} below ground. However, its use has now declined due to problems of tainting of milk, and availability of alternatives.

Control methods

Limited options are currently available in controlling this species. Control measures must be taken in order to prevent its further infestations. Control methods include herbicide application, mechanical control by cutting or mowing, animal grazing or biological control using biocontrol agents.

Response to herbicides

Heracleum mantegazzianum has an extensive rootstock, rapid growth and abundant seed production because of which eradication of groups of these plants is a difficult task (Jones and Russell, 1968; Bhowmik *et al*., 2003). Control measures must be taken in order to prevent its further infestations. The primary measure is public education to dissuade gardeners from planting this striking but noxious plant in their gardens. Plants may be removed prior to seeding to prevent seed dispersal, however, the perennial nature and the toxicity of the plant sap limits mechanical control.

Heracleum mantegazzianum is sensitive to most commercial herbicides including glyphosate, imazapic, triclopyr, dicamba, 2,4-D and clopyralid (Williamson and Forbes, 1982; Page *et al*., 2006; Bowers *et al*., 2011). Treatments usually need to be repeated annually and, in some situations, within the same growing season.

Chemical control options include post-emergence application of growth regulator type herbicides, although limited information on its control is available. However, common growth regulator herbicides such as MCPA or 2, 4-D have little or no permanent effect. Sodium chlorate can be applied to individual plants but the required use rates would have residual effects on soil. Mixtures of the herbicides triclopyr and chlorothalonil or 2,3,6-TBA plus MCPA were also noted to be effective to control *H. mantegazzianum*. The ideal application timing is when there is fresh green growth (*i.e,* April, May or June) and an adequate spray volume should be used to ensure proper coverage (Drever and Hunter, 1970). It may be advantageous to burn the plants before applying herbicides to the remaining vegetation when they have reached a considerable height (Jones and Russell 1968). Glyphosate is an effective herbicide for the control of *Heracleum mantegazzianum* (Davies and Richards, 1985; Bowers *et al*., 2011) but severely damages the flora beneath the weed when used as overall spray.

Heracleum mantegazzianum populations can only be perpetuated via seeds. Control measures applied before flowering and seed set will limit the establishment of subsequent generations and if applied systematically and deplete the reserve seed bank (Caffrey, 1999).

Mechanical control

The perennial nature of *H. mantegazzianum* and toxicity of the plant sap limits mechanical control options. Repeated mowing during the growing season prevented seed production of *Heracleum mantegazzianum* (Roche, 1992). Mowing or scything should be repeated several times during the growing season in order to be effective, but even a single spring cutting can reduce the number and size of seeds (Tiley *et al*., 1996). To reduce the above ground growth of *Heracleum mantegazzianum* both in its vegetative and flowering stages, cutting of leaves was also found to be useful. This method was considered useful to clear riverbanks, pathways and other sites of prolific growth during late summer or spring. Cutting of vegetative plants above ground had only temporal effects and did not provide long-term control. Fresh leaf growth regenerated from the crown bud of the thick storage root within two weeks and a tall canopy was soon re-established (Lundstrom, 1984). Tiley and Philp (2000) concluded that cutting of the flowering stems was not sufficient to prevent perpetuation of *Heracleum mantegazzianum*. Branch development increased as a result of removal of the terminal inflorescence and decreased due to leaf removal. Buttenchon and Nielsen (2007) reported control of *Heracleum mantegazziam* by grazing. While implementing mechanical control, proper protective clothing, including gloves is considered essential. Long handled equipments should be used and work should not be done in direct sunlight.

Bilogical Control

Possible biocontrol agents of *Heracleum mantegazzianum* include cattle, pigs, sheep and goats (Tiley *et al*., 1996; Cock *et al*., 2007), and other natural enemies (Seier *et al.,* 2003; Seier and Evans, 2007). Grazing, especially by sheep, has also been found to be an effective control (Andersen, 1994), although part of this effectiveness may be due to trampling (Morton, 1978). However, complete control of mature plants was not obtained in fields lightly or rotationally grazed by cattle, sheep, or goats. Pig foraging, however, eradicated plants through damage to their roots. Zlobin (2005) described the larvae of *Melanagromyza heracleana* developing as stem-borer of *Heracleum mantegazzianum* in the Russian Caucasus. Recently, three potentially co-evolved pathogens, (*Phloeospora heraclei*, *Septoria heracleicola* and *Ramulariopsis sp. nov*.) are under evaluation at CABI Bioscience UK Center. Field observations indicated that the coleomycete fungus *P. heraclei* might have a high potential as a biocontrol agent due to its significant impact on *Heracleum mantegazzianum* in the form of leafspot and die-back. A new species of Melanagromyza feeding of *Heracleum mantegazzianum* in the Caucasus has been reported by Zlobin (2005). The defense systems of *Heracleum mantegazzianum* and its mutual relationship with aphids and ants have been reported (Hansen *et al*., 2006; Hattendorf *et al*., 2007).

Indigenous pathogens and foraging insects of *Heracleum* spp. have been observed and catalogued in Europe (Bem and Murant, 1979; Sampson, 1994; Burki and Nentwig, 1997; Jakob *et al*., 1998) but possibilities of enhancing the effectiveness of these natural enemies in integrated weed control strategies are only beginning to be explored (Erneberg *et al*., 2003; de Voogd *et al*., 2003). Erneberg *et al*. (2003) and de Voogd *et al*. (2003) have conducted preliminary tests on the fungus *Sclerotinia sclerotiorum* (Lib.) de Bary as a potential bioherbicide. Seier (2003, 2005) has screened numerous fungi collected from *H. mantegazzianum* in its native range and found three promising candidates for biological control: *Phloeospora heraclei* (Lib.) Petr., *Ramulariopsis* sp. and *Septoria heracleicola* Kabat & Bubak.

In Europe, many insect species have been recorded on *H. mantegazzianum*. Jakob *et al*. (1998) recorded 55 species on *H. mantegazzianum* in Switzerland, mainly in sunny, lowland sites but none appeared to significantly affect plant health.

Public awareness

Public awareness on invasive species is critical for effective management. Nielsen *et al.* (2005) provided a useful section on preventive measures, early detection and eradication, providing a checklist of actions, from the establishment of policies and guidelines, identification of routes of possible entry, identification of habitats most at risk, awareness campaigns, surveys of incidence and spread, eradication campaigns where necessary, followed up by monitoring. They suggest that mapping of incidence and spread is made easy by the size and conspicuousness of the weed, ensuring that the public can provide reliable help, and even allowing clear monitoring from aerial photographs taken when the weed is in flower (Mullerova *et al*., 2013). A successful project of public participation GIS involving school students monitoring *H. mantegazzianum* in Latvia has been reported by Fonji *et al*. (2014).

In summary, *Heracleum mantegazzianum* is a noxious and invasive species that has the potential to move into agricultural areas in the United States and many countries around the world. It is both a public health and environmental hazard, since humans, as well as animals are sensitive to its sap. The usefulness of this plant as horticultural value should be banned. Public awareness and education on identification, early detection and eradication are also considered important to reduce its new invasion and spread in agricultural and urban environments.

Note:

[2] <http://www.giant-alien.dk/pdf/Giant_alien_uk.pdf>

[3] <http://gardening.wsu.edu/column/07-05-98.htm>

[4]<http://dnr.metrokc.gov/weeds>

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