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THE FIRST REPORT OF THE INVASIVE ALIEN WEED JERUSALEM ARTICHOKE (*Helianthus tuberosus* L.) IN THE REPUBLIC OF NORTH MACEDONIA

SUMMARY

A population of Jerusalem artichoke (*Helianthus tuberosus* L.), an invasive plant A population of Jerusalem artichoke (*Helianthus tuberosus* L.), an invasive plant species native to North America, was recorded in 2016 near Gradište and along the regional road R 1204 (Gradište, Skačkovce, Dobrošane and Kumanovo) in the northern mountainous part of the Republic of North Macedonia. *H. tuberosus* is a new species that is alien to Macedonian flora. Surveys revealed intensive growth and low- to medium-density populations of *H. tuberosus*. The population density was not quantified, but several stands of different sizes were found. An ecological risk assessment based mainly on knowledge about historical invasions in north-western and central European countries showed that this species is a serious threat to Macedonia’s biodiversity. Biological invasion of *H. tuberosus* affects global biodiversity, and the invaded ecosystems may suffer from significant loss of economic and cultural value. Specifically, is a threat to biodiversity in wet habitats, natural and extensively managed habitats, riparian areas and swamps. It grows best in habitats that are repeatedly disturbed by floods (i.e. riparian areas), but it may also occur in ruderal and agricultural environments. Although many herbicides can be used to control *H. tuberosus*, their use is limited as the plants are often near waterways, where use of herbicides is not recommended. Other control methods are time-consuming and can be quite costly.

Keywords: invasive weed, environmental impact, control, forecast, Republic of North Macedonia

INTRODUCTION

The Jerusalem artichoke (*Helianthus tuberosus L.*) (syn. *Helianthus tomentosus* Michx.), which is also called the topinambur (Alex et al., 1980), sunchoke, sunroot, girasole, Canada potato, fusichoke, sunroot, or earth apple

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(Wyse and Wilfahrt, 1982), is an angiosperm, C3 warm-season plant species of *Asteraceae* (*Compositae*) family (Monti et al., 2005; Tassoni et al., 2010). Kosaric et al., 1984) reported that there are about 102 common names associated with *H. tuberosus*.

The genus *Helianthus* contains some 70 species, which are annuals, herbaceous perennials or shrubs in North, Central and South America (Rehorek, 1997). H. *tuberosus* is a perennial that is grown as an annual (Anonymous, 2011). According Verburg et al., (1996) and Crawley (1997) *H. tuberosus* belongs to "pseudoannual" group: the death of the whole plant occurs by the end of vegetation, except stem tubers in the soil, from which new shoots – showing total genetic identity with the mother plant – will emerge on the next spring. They are considered as clonal plants without continuous inter-clonal relations in time.

H. tuberosus is a native of North America (Cosgrove et al., 1991) and is thought to have originated in the Great Lakes area (Simmonds, 1976) or possibly in the Ohio and Mississippi River valleys (Wyse et al., 1986). Some authors referred to *H. tuberosus* as being native also in Canada (Swanton et al., 1992). Munro and Small (1997) stated that plants found at wild or ruderal sites in Canada would be escapes from cultivation and distributed to many countries of the world (Swanton et al., 1992). It is unclear whether *H. tuberosus* was used only from wild plants or whether it had already been domesticated when encountered in the region of Massachusetts by Samuel de Champlain in 1605 (Heiser, 1978). Once established, *H. tuberosus* is able to outgrow its competitors as it reaches great heights in a short period of time and thereby shades other plants that are living in the close vicinity (Swanton and Cavers, 1989).

The cultivated forms may have developed in southern Canada, from where they were dispersed to Western Europe early in the 17th century and subsequently to other temperate parts of the Northern Hemisphere (Scoggan, 1979; Kompała-Baba et al., 2005). The first escaped plants were found in the mid 19th century in some countries, the invasive spread began mostly around 1900 and became more rapid in central Europe in the 1930s (Hartmann et al., 1995; Fehér and Končeková , 2001). In the second half of the 20th century it became a serious invasive alien species (Ludwig et al., 2000; Balogh, 2006), and also a common weed problem (Balogh, 2001; Konvalinkova, 2003; Rehorek, 1997) in all parts of Europe. It is on the EPPO list containing the names of the most 34 dangerous invasive species.

In the past it was considered as a typical weed of natural and semi-natural conservation areas. It can locally occur on alluvial weed communities and, due to its intensive vegetative reproduction capacity and shading effect, it can create homogenous stands also (Balogh, 2006). Once established, *H. tuberosus* plants exhibit a rapid increase in plant height, number of leaves and tubers through one life cycle (Swanton and Cavers, 1989). This robust growth habit enables *H. tuberosus* to outcompete most other plant species in arable land. Allelopathy as a type of interference among higher plants is also believed to play an important role in its intensive spreading (Tessio et al., 2010). This is the first document about the presence of invasive *Helianthus tuberosus* L. in Republic of North Macedonia.

General Description
(*Helianthus tuberosus* L.) (syn. *Helianthus tomentosus* Michx.)

The Jerusalem artichoke (*Helianthus tuberosus* L.) is an erect, rhizomatous perennial herb, up to 3-4 m high, scarcely to moderately branched in upper half of stem, hirsute in most above-ground parts. The root system is adventitious (in plants not grown from seed), fibrous and develops cord-like rhizomes that can reach more than 1 m in length. The apical part of the rhizome is swollen and forms a fleshy tuber. Tubers formed by thickening of short and stout or long and slender underground stolons, ellipsoid to globose, 2-8(-15) x 3-6 cm, whitish, yellow, red or purple, with small scale leaves and axillary buds. Leaves opposite or in whorls of three in lower plant part, in upper part alternate, simple; petiole 2-4 cm long, winged above; blade ovate to ovate-lanceoliate, 10-20 cm long, base tapering into petiole, margin irregularly serrate, apex acute, veins prominent with three main veins.

The inflorescence is a pseudanthium borne alone or in groups at the end of the stem or on terminal axillary branches. The flower head is 5-11 cm in diameter (much smaller than that of the sunflower) and bears many small yellow tubular fertile flowers surrounded by yellow ray sterile flowers, the ligules of which are thought of as petals. Fruit an achene, oblongoid, containing a mottled black or brown seed, 5-7 mm long, flattened at the sides, brownish with dark stripes, thinly hairy (Kays et al., 2008; Fnaec, 2006).

Phenology

In temperate regions, *H. tuberosus* requires at least 6.7ºC of soil temperature for sprout development (Kays and Nottingham, 2007), and cold temperatures are needed to break dormancy (5°C or less) (Denoroy, 1996). Kays and Nottingham (2007) noted that *H. tuberosus* is a photoperiod-sensitive short-day plant that requires long light periods followed by shorter light periods to trigger the shift to reproductive stage of development. In addition, temperature is also important factor affecting floral buds and inflorescence formation (Fenner, 1998; Hassan et al., 2005; Dasumiati et al., 2015). Several reports indicated that low temperature delayed floral bud formation in many plant (Konvalinková, 2003; Kaleem et al., 2010). Therefore, floral bud formation needs sufficiently high temperatures. A cooler temperature can result in a return to vegetative growth. Thus, short day reduced the number of days to flowering.

H. tuberosus is diploid (2*n* = 102) (Duke, 1978), and seed production varies with clone (Konvalinková, 2003) and usually wild clones produce 5 seeds per flower (Kays and Nottingham, 2007). *H. tuberosus* grown in temperate regions had maturity of 125-150 days (Kays and Nottingham, 2007).

MATERIAL AND METHODS

First record in Republic of North Macedonia

On 13th of August 2016, a visit to maize field trials with herbicides located in the Northern mountainous part of the Republic of North Macedonia (Fig. 3) near the village Gradište (Latitude: 42° 1' 23.82" N, Longitude: 21° 53' 9.48" E) and alongside the regional road R 1204 (Gradište, Skačkovce, Dobrošane and Kumanovo) (Fig. 4), revealed an intensive growth of Helianthus tuberosus L. (Jerusalem artichoke), a new alien species to the Macedonian flora.

Figure 1. *Helianthus tuberosus* L. (Jerusalem artichoke) (Photo by Z. Pacanoski)

Figure 2. High dense population of *H. tuberosus* growing in the man-made habitats (Photo by Z. Pacanoski)

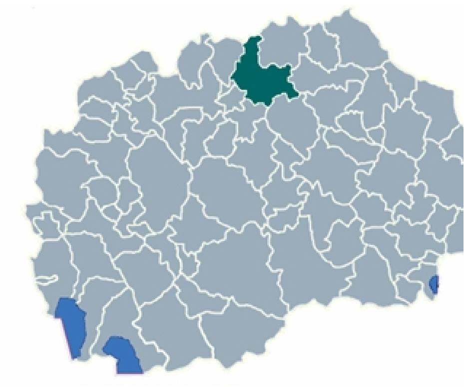

Figure 3. Maping of *Helianthus tuberosus* L. (Jerusalem artichoke)

Figure 4. Satellite map of the regional road R 1204

Figure 5. Population of invasive *H. tuberosus* growing in the man-made habitats alongside the regional road R 1204 (Photo by Z. Pacanoski).

Figure 6. Population of invasive *H. tuberosus* growing alongside the regional road R 1204 (Photo by Z. Pacanoski).

On the 30th of September 2016, the site was surveyed to estimate the extent of the invasion. These surveys revealed an intensive growth (intensive flowering stage) and a low to medium dense population of *H*. *tuberosus*. The population's density was not quantified, but several stands of different sizes were found. The largest stands were approximately 10-15 metres at their widest point. During the second survey, extended the area of observation, and the plant was found mainly in human influenced and man-made habitats such as roadsides, ruderal areas, wastelands near the regional road R 1204, house yards as ornamental plant and river-bed of the Kumanovska Reka (Kumanovo river, Fig. 5. 6. 7. and 8).

Figure 7. Population of invasive *H. tuberosus* growing alongside the River-bed (Photo by Z. Pacanoski).

Figure 8. Population of invasive *H. tuberosus* in the man-made habitats alongside the regional road R 1204, (Photo by Z. Pacanoski)

The green area in the map is the area of the country where the villages Gradište Skačkovce, Dobrošane and city Kumanovo are situated and where the plants were observed and the blue areas are lakes.

RESULTS AND DISCUSSION

Similar to our findings, *H. tuberosus*, according to Alex and Switzer (1976), Gleason and Cronquist (l99l), is frequently found in moist habitats such as river and stream banks, meadows and waste areas, as well as in cultivated fields and orchards (Wyse et al., 1986; Wall and Friesen 1989).

H. tuberosus phytocoenoses occupy refuse dumps, edges of allotments and roadsides, urban wastelands or sites where the fresh soil layer was deposited. They do not cover large areas and can be found in the mosaics with ruderal or nitrophilous plant communities (Kompała-Baba et al., 2005).

Kopecký (1985), Hejný et al., (1979), Oberdorfer (1983) (cit. by Kompała-Baba et al., 2005) placed *H. tuberosus* stands from the ruderal sites into the *Eu-Arction,* the *Dauco-Melilotion* or the *Aegopodion podagrariae* alliances. Species commonly associated with *H. tuberosus* in two grassland populations, mown once per year, in London Ontario are: *Saponaria officinalis* L., *Daucus carota* L. *Elytrigia repens* (L.) Nevski., *Asclepias syriaca* L., *Dactylis glomerata* L., *Achillea millefolium* L., *Trifulium pratense* L., *Plantago lanceolata* L., *Glechoma hederacea* L., *Taraxacum officinale* Weber, *Poa* spp., *Vicia* spp. and *Galium* spp. Weed populations of *H. tuberosus* in southern Ontario have been found in corn, soybean and small grain fields. They are associated with other common weeds such as *Chenopodium album* L., *Amaranthus retroflexus* L., *Amaranthus powellii* Wats., *Abutilon theophrasti* Medic., *Setaria viridis* (L.) Beauv., *Ambrosia artemisiifolia* L. and *Sonchus* spp.

Nearly all documented research concerning *H. tuberosus* applies to areas between latitudes 30 and 50°N. It grows in places where annual precipitation ranges from 310 mm to 2820 mm (mean of 40 cases = 1001 mm) and where annual temperatures are between 6.3°C and 26.6°C (mean of 40 cases = 13.3°C) (Duke, 1979). Favourable climatic conditions might seem to be a key predictor of *H. tuberosus* distribution in Republic of Macedonia. In that context, the place where it was found belongs to region with medium annual precipitation (564 mm) and mean year temperature of 12.6°C (Kostov, 2003). Also, it does well in most soils with pH ranging from 4.5 to 8 (mean of 37 cases = 6.4) and may tolerate salinity. However, it prefers loose, loamy and well-drained soils and is completely naturalized on moist, nutrient-rich, sandy or loamy soils, especially along rivers (Hartmann et al., 1995). Though the plant is tolerant of winds, saline ones have deleterious effects. However, it tends to deplete soils (Kays et al., 2008; FNA, 2006).

Taking into consideration that, *H. tuberosus* was found in human influenced and man-made habitats in border region, probably the introduced pathway may have been human activity. The place of starting point of the invasion was at the Northern part of the Republic of Macedonia much closed to the Serbia, where *H. tuberosus* is consider as one of the most widespread alien plant species (Stanković-Kalezić et al., 2007; Vrbničanin et al., 2009; Vrbničanin, 2013).

H. tuberosus was brought to Europe for the first time in 1607. Early in the 17th century it was distributed to several European countries: the first plants were mentioned in France, in 1614 it was brought to the Netherlands, 1614 to Italy, 1617 to England and 1627 to Germany. Whereas the motive for the first introduction may have been botanical curiosity, it was soon grown for the edible tubers on a large scale. In the mid-18th century it was widely replaced by the potato as a staple food in central Europe.

The first escaped plants were found in the mid 19th century in some countries, the invasive spread began mostly around 1900 and became more rapid in central Europe in the 1930s (Hartmann et al., 1995). Today, it is cultivated and escaping, often invasive, in many temperate areas in Europe, Asia, New Zealand, and tropical South America (Weber, 2003).

Environmental impact

The discovery of a well-established population of *H. tuberosus*, as a highly invasive alien species in the Macedonian flora, is a significant concern, particularly in the Northern part, where dense stands of *H. tuberosus* monoculture were recorded (Fig. 1 and 2). Biological invasions of *H. tuberosus* affect biodiversity worldwide (Kosaric et al., 1984), and, consequently, the invaded ecosystems may suffer from significant losses in economic and cultural values.

As the species with potentially high negative influence on biodiversity, *H. tuberosus* is the threat to biodiversity in wet habitats, natural and extensively managed habitats (Hartmann et al., 1995; Kowarik, 2003), riparian areas and swamps, as the plant which is able to successfully compete directly with native species for space, light and nutrients (FNA, 2006; Duke, 1983). It grows best in habitats repeatedly disturbed by floods (riparian areas), but may also occur in ruderal and agricultural environments (Zganciková et al., 2012).

In Western European climatic conditions (Belgian, for example), the plant does not produce viable seeds and propagates vegetative. Tubers and pieces of rhizomes are transported with rodents and flowing water, especially winter floods. It is in strong expansion in neighbouring countries, especially in France, Germany and Switzerland. *H. tuberosus* is abundant in natural settings, such as riverbanks of European countries (Schnitzler et al., 2007), especially in Austria (Walter et al., 2005), Croatia (Vendula, 2008), Slovakia (Fehér, 2007), and Ukraine (Protopopova et al., 2006). The plant can produce dense and persistent monospecific populations along rivers, river banks and floodplains where it outcompetes native species, slows down natural colonisation by trees and favours river bank erosion (Krippel and Colling, 2006; Pfeiffenschneider et al., 2014). Invasive populations on river banks can result in damage to flood protection constructions, which can impact on the environment. It produces phytotoxic compounds and can be as competitive as *Fallopia japonica* in alluvial habitats.

H. tuberosus can be a weed of agricultural fields either by invading fields such as forage crops (Park et al., 2001) or when it is used as a crop in crop rotation systems. As not all tubers are removed in harvesting, *H. tuberosus* infests the consecutive crop as a volunteer weed, which can reduce the yield of maize, sugar beet and soybean by 25, 81 or 91%, whereas the yield reductions in wheat, oat, rape and ryegrass were insignificant (Swanton, 1994; Schittenhelm, 1996). Wyse and Young (1979) found that densities of 4 tubers/m of row of *H. tuberosus* reduced corn seed yields by 16-25%. Wyse et al., (1986) found that *H. tuberosus* densities of 1, 2 and 4 tubers per metre of row reduced soybean seed yield by 31, 59 and 77%, respectively.

Soybean height, branches per plant, pods per plant and total seed weight were all reduced by the presence of *H. tuberosus* (Wyse et al., 1986). Soybean leaf area and relative growth rate were reduced by densities of 2 and 4 artichoke tubers per metre of crop row and net assimilation rate was reduced by 4 tubers per metre of crop row (Wyse et al., 1986). Wall and Friesen (1989) found that 4-6 surviving *H. tuberosus* shoots per square metre could reduce seed yield in barley by 20%. *H. tuberosus* may also occur in pastures, but its high nutritional quality may render its presence desirable (Seiler 1988).

The success of *H. tuberosus* as an invasive annual species could be due to the biological factors within diverse habitats which include: (i) a high expenditure of energy on initial growth of stem, branches and leaves; (ii) a large amount of energy allocated to the production of rhizomes and tubers; (iii) a phalanx-like growth morphology, facilitating capture of both above- and below-ground resources; (iv) mobility of nutrients within the plant; (v) seed production; (vi) the ability to regenerate even if severely defoliated; and (vii) the constancy of nutrient allocation to clonal structures (Swanton and Cavers 1989). These factors are complemented by resistance to most diseases and pests, and tolerance of poor soils (Kosaric et al., 1984).

Mechanical Control

Invasive populations in Germany were successfully controlled by various mechanical methods: mowing twice a year in late June and in August gave good control after 2 consecutive years (Wagner, 1988). Large areas can be mowed with agricultural machinery where the soil permits, small infestations or those on soft soils were treated with hand-held trimmers or brush cutters.

Removing the mowed plants did not result in better control. Faster success may be reached by cutting in June and light cultivation. Close monitoring for the right timing is essential: it must be done when the tubers formed in the preceding year are consumed, and new ones have not formed (Hartmann et al., 1995). In light soils, plants can be hand pulled in October or in early spring; if this is done in late spring, too many tubers remain in the soil. In Hungary, efficacy of mowing for *H. tuberosus* control was investigated in the latest years (Fehér and Konĉeková 2012). Balogh (2006) suggested mowing more times within a year when plant shoots reach 50 cm height. Physiological background of this is that the food reserves of the tubers will deplete until June. Stem tubers of the previous year will destroy from the end of April and entirely die by the end of June (Swanton et al., 1992). Plants use food reserves mainly for the development of the new shoots. The mowing cut the shoots, therefore the possibility or the plants to develop new propagula will considerably decrease.

Tilling in the early summer can help to weaken the weed potential of *Helianthus tuberosus* (Swanton, 1994). Swanton and Cavers propose disking or rot tilling during periods of minimum regeneration.

Chemical Control

Glyphosate and dicamba were both found to give good control of *H. tuberosus* in forage crops in Korea (Park et al., 2001). As a weed, it must be controlled early. Wyse et al., (1986) recommended that in soybeans, *H. tuberosus* growth be controlled within 6 week of planting because of its strong competitive ability. Both rhizomes and tubers can overwinter in the soil and produce shoots the following year (Vanstone and Chubey, 1978).

Application of glyphosate treatments two times in the growing season ensured a 100% weed control effect on *H. tuberosus* in glyphosate resistant soybean fields. Because of the presence of the non-shot forth, dormant tubers *H. tuberosus* control is suggested even after two years (Kays and Nottingham, 2008). Very good (96%) *H. tuberosus* control efficacy was obtained when combined herbicide treatments with glyphosate isopropylamin salt + 2,4 D were applied in autumn after mowing (Labant-Hofman and Kazinczi, 2014).

Also, Swanton (1982) suggested that greater than 90% control of both top growth and re growth of new shoots could be achieved in corn using split applications of dicamba at 0.28 kg a.i./ha or dicamba plus 2,4-D plus mecoprop at 0.55 kg a.i./ha, provided that the split application was separated by a period of 10-14 days. Wall et al., (1986) found that *H. tuberosus* was controlled in barley by a post emergence application of clopyralid at 1.0 kg a.i./ha, or clopyralid at 0.5 $kgha^{-1}$, if combined with 0.5 kg a.i./ha of 2,4-D, or dicamba at 0.2 kg a.i./ha plus 2,4-D at 0.4 $kgha^{-1}$. The combination of clopyralid and 2,4-D was the most effective (Wall and Friesen 1989). Chemical control is most effective at the pre bloom stage of growth. Both top growth and tuber re growth are controlled and further infestation is reduced (Swanton 1982).

CONCLUSIONS

Helianthus tuberosus L. just has been found in Republic of North Macedonia to some initial degree of invasion. However, in some areas, particularly in north-western and Central Europe, it has spread fairly widely and is well established and has become the target of large scale removal campaigns. The climate and topography of the many European regions are favourable for it’s grow and expansion. In other Macedonian locations with similar climates to the northern part where *H. tuberosus* was found, it could potentially detected new plants of this species.

Both, vegetative and generative propagation contribute to its invasive potential. Spread is also facilitated by waterways and human transportation. Although many herbicides can be used to control *H. tuberosus*, their use is limited as the plants are often near water ways where herbicide uses is not recommended. The other control methods, however, are time consuming, and could be quite costly.

The prognosis for curbing the spread of *H. tuberosus* in Republic of North Macedonia seems impossible. In very close future, it will rapidly establish itself along rivers, river banks and floodplains, as well as ruderal and agricultural environments in many other Macedonian regions, following the pattern seen over the past three centuries in north-western and Central Europe.

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