Distribution and Management of *Heracleum* species in Reykjavík, Iceland

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Faculty of Life and Environmental Sciences
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30 ECTS thesis submitted in partial fulfillment of a
Magister Scientiarum degree in Environment and Natural Resources

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Abstract

Invasive alien species can negatively impact ecosystems in a number of ways that include declines in biodiversity, economic losses, human health issues, and risks to native species. Given these impacts, the City of Reykjavík, Iceland, is concerned about three alien hogweed species: *Heracleum mantegazzianum, H. persicum,* and *H. sphondylium*. To assess this concern, these species were mapped in 11 districts in Reykjavík between May and August 2017 on both managed and unmanaged sites, using ArcGIS. The study also focused on the area of Laugarnes, where vegetation cover was measured and efforts to eradicate *H. mantegazzianum* were implemented in June 2017. Overall, hogweed was found in 53 public land locations and 70 private land locations. Results indicate that *H. mantegazzianum* is abundant and widely distributed in Laugarnes. *H. sphondylium* is prevalent in Vesturbær and is spreading at a faster rate than *H. mantegazzianum.* This is the first time *H. sphondylium* is being recorded as an invasive species in Iceland. *H. persicum* is not a threat at this time but should be monitored. Key findings reveal early detection and monitoring of the species and surrounding plant community is needed to reduce the threats and costs of hogweed control, so the City of Reykjavík can adopt more focused and effective management strategies. Finally, public interaction and participation is important to increase community awareness and support towards future management decisions regarding invasive species.

Abstract in Icelandic

Framandi ágengar tegundir eru sívaxandi ógn fyrir vistkerfi og geta haft alvarleg áhrif á velferð líffræðilegrar fjölbreytni en einnig á heilsu fólks og efnahag. Í Reykjavíkurborg hefur hópur framandi plantna, tröllahvannir af ættkvíslinni *Heracleum,* vakið áhyggjur. Um er að ræða þrjár tegundir – *H. mantegazzianum*, *H. persicum* og *H. sphondylium*. Til að meta núverandi ástand var útbreiðsla þessara þriggja tegunda í Reykjavík kortlögð sumarið 2017 með notkun landupplýsingatækja (ArcGIS), bæði á borgarlandi og einkalóðum. Eitt svæði, Laugarnestangi, var tekið til sérstakrar skoðunar og gróðurþekja á svæðum þar sem *Heracleum* vex var metin með tilliti til tegundasamsetningar. Niðurstöður gefa til kynna að *H. mantegazzianum* er útbreidd um borgina og sums staðar í miklum mæli m.a. á Laugarnesi. *H. sphondylium* er mjög algeng í Vesturbæ en annars með nokkuð takmarkaða útbreiðslu sem fer þó ört vaxandi. *H. persicum* er mun sjaldgæfari. Niðurstöðurnar eru grunnforsenda fyrir skipulag og framfylgd aðgerða til að stemma stigu við frekari útbreiðslu tröllahvanna í Reykjavík.

Table of Contents

List of Figures

Chapter 1

Chapter 2

List of Tables

Chapter 1

Chapter 2

Acknowledgements

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1. Hogweed in Reykjavík

1.1 Introduction

An invasive species is defined as a species that is alien (i.e., non-native) to the ecosystem under consideration; and, "whose introduction does or is likely to cause economic or environmental harm or harm to human health" (ISAC, 2006). Invasive species encompass an ample spectrum of taxonomic groups of aquatic and terrestrial plants and animals: therefore, we need to understand the impacts of alien invasions on plant communities. (Finch et al., 2009).

In general, an invasive species can present a vast issue in any given area and become a key driver of ecosystem degradation. It can also have a considerable social impact in human settlements. Invaders can have a significant and consistent effect on populations, communities, and ecosystems (Cameron et al., 2016); and can impact the environment through a loss of biodiversity, affecting the survival of native species. Risks to the society include economic losses and possible human health issues. Clavero and García-Berthou (2005) found that species extinction is usually a consequence of invasions; suggesting that prevention and the precautionary principle are of relevance regarding invasive species (Clavero et al., 2005).

Vilà and colleagues (2011) looked at the impact of invasive species on biodiversity community properties and ecosystem processes through a meta-analysis of 199 articles describing the effects of 135 alien plants. The study aimed to assess if ecosystems on an island are more at risk to impacts of alien invasive species than ecosystems found on mainland ecosystems. Evidence was found that alien plant species do impact various ecological processes depending on level of ecological complexity (Vilà et al., 2011). Another important key finding was that increased production and proliferation of an alien plant species occurred simultaneously with a decrease in the native place species diversity- implying a relationship between the two factors (Vilà et al., 2011). This finding is an example of how an alien invasive plant species can impact the environment through the loss of biodiversity. Although this study did not find a significant difference in impacts between mainland and island ecosystems, any loss of biodiversity should still be monitored for continued comparison and tracking of both native and non-native plant communities overtime. In an island ecosystem such as Iceland and in the Arctic in general, invasive alien species are a major threat that need to be monitored due to geographic position, delicate and relatively low native flora, climate change, and anthropogenic activities both in the country and in the region (CAFF & PAME, 2016). Kumschick and colleagues (2015) assessed the environmental impacts of invasive species in order to direct and develop an appropriate management action. They used the GISS semi-quantitative generic impact scoring system which is made up of 12 categories to score the environmental impact of 300 species from five major taxonomic groups: mammals, fish, plants, terrestrial arthropods and birds (Kumschick et al., 2015). Out of the 300 species, 128 of the species were plants. The study found that overall, mammals had the highest impacts, while plants and fish had the lowest impacts. However, Kumschick and colleagues (2015) also concluded that plants always had a higher environmental impact than a socioeconomic impact. This type of risk assessment is helpful to identify invasive species, quantify and

prioritize their environmental impacts, and effectively allocate resources to minimize their effects (Kumschick et al., 2015). Both an environmental and socioeconomic assessment of the impacts of invasive species are essential when developing a management or eradication plan.

Alien species can have an effect on ecosystem services and well-being (Vilà et al., 2010). When these ecosystem services are interrupted, ecosystems face risks of degradation or even collapse. Within Europe, the Delivering Alien Invasive Species Inventories for Europe Database records 12122 alien species (DAISIE 2018). An evaluation of alien species impacts in Europe found 1094 species having ecological impacts and 1347 species showing economic impacts, many of which were terrestrial plants and invertebrates (Vilà et al., 2010). Vilà and colleagues (2010) note that the number of impacts by alien species increase along with the number of ecosystem services that are affected. Hence, leading to a key finding that alien species usually have various types of impacts that are not just limited to one ecosystem service (Vilà et al., 2010). Given this positive correlation and the threats that invasive species pose to biodiversity, it is crucial to manage them through prevention, eradication and control strategies to minimize their impacts.

The urban environment is a key factor in the ecology of invasive species and actions by city administrations and other active parties are highly important when addressing the risks of biological invasions and reacting to them. Citizen awareness and participation is one element that is useful in urban settings due to the visibility and proximity of invasives as they are often present in public city spaces (Scalera & Genovesi, 2013). It is well documented that urban areas are hotspots for invasive species, as they are often the site of entry for invasive species during their dispersal between regions, countries, or continents (Stajerova et al., 2017; Scalera & Genovesi, 2013). Stajerova´s key findings on spatial distribution of invasive species in urban areas conclude that the different invasive species prefer habitats around the city center; and that the spatial structure and quality of the habitat need to be assessed when drafting management efforts (Stajerova et al., 2017). Habitat quality needs to be considered because one area can vary greatly in species richness and abundance from another area in the same city or similar environment. This is an important consideration when studying hogweed (*Heracleum)* species within the city borders of Reykjavík addressed in this study as described later. Stajerova´s study aimed to observe the differences between an ecosystem within the downtown city borders and an ecosystem outside of the city center. Understanding the spatial distribution of an invasive alien plants is essential for both current and future land management within an urban environment and when developing restoration and management plans (Stajerova et al., 2017).

The way in which invasive species are disposed of in an urban area during eradication can also have a huge impact on the spread and risk of biological invasions. For example, Plaza and colleagues (2018) found that a dump can foster and support populations of both alien and invasive species worldwide, which "produce multiple economic, environmental, and health impacts" (Plaza et al., 2018). In addition, they hypothesized that dumps may facilitate the spread of these species to the surrounding landscapes as well as distant sites (Plaza et al., 2018). Therefore, it is extremely important to be aware of potential plant invasions and risks to human health when disposing of invasive plants in urban areas. (Pyšek et al., 2003).

The impact of an invasive species is more prominently recognized when it involves a disturbance or a threat to human health (van Ham et al., 2013). For example, the invasive plant Sosnowsky's hogweed (*Heracleum sosnowskyi*) was introduced in the 1950s for

agriculture in Estonia (Tillemann 2013). This hogweed had spread to 1258 ha in 2009, which included some densely populated areas. Sosnowsky's hogweed, like other hogweed species, has a public health risk because it generates a photoxic sap that can burn the skin (Nielsen et al., 2005; Tillemann 2013). Given this health risk and that this plant is also spreading along rivers, the distribution of Sosnowsky's hogweed is being tracked in a public database, facilitating management efforts and collaboration with stakeholders such as local authorities, landowners and environmental groups (Tillemann 2013). In Reykjavík, Iceland, three hogweed species – giant hogweed (*H. mantegazzianum*), Persian hogweed (*H. persicum*), and common hogweed (*H. sphondylium*) - are recognized as current or potential alien invasive species. All three hogweed species also contain a harmful phototoxic sap that can leave permanent scars and cause blindness (Nielsen et al., 2005). Research indicates that the risk of photoxicity varies between hogweed species because of differences in the amount and composition of furanocuomarins in the sap (Cieśla et al. 2008). An assessment in 2016 revealed that giant hogweed, Persian hogweed, and common hogweed were growing in numerous open areas in Reykjavík, including playground areas, schoolyards, and protected wilderness areas (S. Sigurðsson, unpublished data). Furthermore, based on herbarium records and observational data, Persian hogweed was only documented in northern Iceland prior to the assessment (Wasowicz et al., 2013; IINH 2018). The widespread distribution of these alien, potentially invasive species, along with the health risks they pose, makes them a high priority for further assessment in Reykjavík (S. Sigurðsson, unpublished data).

A better understanding of the distribution of giant hogweed, Persian hogweed, and common hogweed in Reykjavík is needed, as well as the best ways to manage these species. Similarly, there is a need for public awareness and education on the health risks of hogweed. The main goals of this study were to map the distribution of all three hogweed species within the borders of Reykjavik throughout the summer of 2017, and compare the distribution in 2017 with the distribution and eradication efforts from the assessment in 2016. The data generated from this study will be useful to assess and understand the current and potential impacts that the invasive plant species have on the local, native plant diversity in both urban and wilderness areas. This information will help guide management efforts, including eradication and control actions, which often require several years of implementation and are important to start early in the invasion process. Moreover, this study will help develop public awareness campaigns regarding hogweed, as well as assess some of their impacts.

1.2 Methods

1.2.1 Target species

The study focused on three hogweed species that have been introduced in Reykjavík. The first species was giant hogweed (Bjarnarkló; *H. mantegazzianum*), which is native to Russia and Georgia and the first known record in Iceland is from 1997 (Nielsen et al., 2005; Wasowicz et al., 2013) although suspected to be introduced much earlier, possibly in the 1950s. This naturalized plant has been found in southern, western, northwestern and northern Iceland (Wasowicz et al., 2013; IINH 2018). Giant hogweed is a biennial or monocarpic perennial that relies on habitat areas with rich soils and sufficient water supply (Tiley et al, 1996). For example, giant hogweed often occurs in abandoned meadows, unused and disturbed edges alongside of roadways, railways, waste grounds, and if conditions are sufficiently moist along watercourses and on river banks (Tiley et al, 1996).

A discriminating feature is that it typically grows to 2-3 m but can grow between 4-5 m high. Being a monocarpic plant, it dies after flowering. Stems are normally 5-10 cm in diameter and contain purple spots. The leaves can grow up to 3 m in length with 1-2 pairs of leaflets, having elongate, biserrate lobes (like a saw); with the teeth on the leaf margins showing concave sides curling toward the center of the lamina or tooth (Jahodová et al., 2007). When flowers are present (between June through August), the umbels are white in color and in a cluster approximately 80 cm across that contain 30-150 rays. Over 80,000 flowers can occur on a single giant hogweed plant (Nielsen et al., 2005). The umbels are rather flat, and the rays have "narrow, translucent, patent papillae and/or glandular hairs" (Jahodová et al., 2007). The fruits of giant hogweed are "elliptical, winged and dispersed mostly by wind, water and human activities. The majority of ripe fruits fall close to mother plants. For plants 2-m high, 60–90% of fruits fall within a radius of 4 m from the mother plant" (Nielsen et al., 2005). On average, a mature giant hogweed plant can potentially produce more than 50,000 seeds (Tiley and Philp, 1994). This highlights a need to manage the species as its dispersal potential is very high.

The second species studied was Persian hogweed (Tröllakló; *H. persicum*), a species native to Turkey, Iran and Iraq (Jahodová et al., 2007). The oldest record of this naturalized plant in Iceland is from 2001, and it is currently present in northern and western Iceland (Wasowicz et al., 2013; S. Sigurðsson, 2016 unpublished data; IINH 2018) but is also suspected to have been introduced at an earlier time. Persian hogweed is a true perennial plant that will live for more than 2 years. Discriminating features include having often more than 1 stem and a continuous violet color on the lower part of the stem (Often and Graff, 1994). The leaves are more elongate than the leaves of the giant hogweed and have 2-3 pairs of leaflets, with broad, short lobes. The teeth on the leaf margins are short, with convex sides that curve away from the center of the lamina or tooth. Umbels are rather convex, and the rays have "broadly triangular whitish ascending papillae, and usually no glandular hairs" (Pysek et al., 2007). Persian hogweed flowers more than once (Often and Graff, 1994). The flowers have outer petals with rather broad lobes and the ovaries/fruits usually have a dense covering of more than 1 mm long, whitish hairs and slightly expanded dorsal vittae, or oil tube (Jahodová et al., 2007). The persian hogweed plants found in Reykjavík were approximately 3 m in height (S. Sigurðsson, unpublished data).

The third species studied was the common hogweed (Húnakló; *H. sphondylium*), a plant native to Europe, Asia and northern Africa (EOL 2018). Wasowicz et al. (2013) report common hogweed as a casual alien plant present in western Iceland, with its first record in 2002; however, also suspected to have been introduced to Iceland around 1950. Common hogweed is a polycarpic perennial that grows about 2 meters tall and has stems that usually do not grow over 2 inches in diameter (Sheppard, 1991). *Heracleum sphondylium* is known to have a high tolerance against wind, humidity, and atmospheric salinity (Sheppard, 1991). Like giant hogweed, the umbels are white in color. However, the number of stems on each umbel of common hogweed will not be higher than about 20, whereas giant hogweed can be >50. The stems of the common hogweed lack the purple spots found on giant hogweed. The leaves are also generally smaller, less shiny, and more rounded. At this time, insufficient information is known about the presence and distribution of common hogweed in Iceland.

Figure 1.1: ***H. persicum & H. mantegazzianum.*** (Persian Hogweed and Giant Hogweed). Shown are distinguishing features of the leaves and fruits. *Photo credit: Monika Osterkamp*

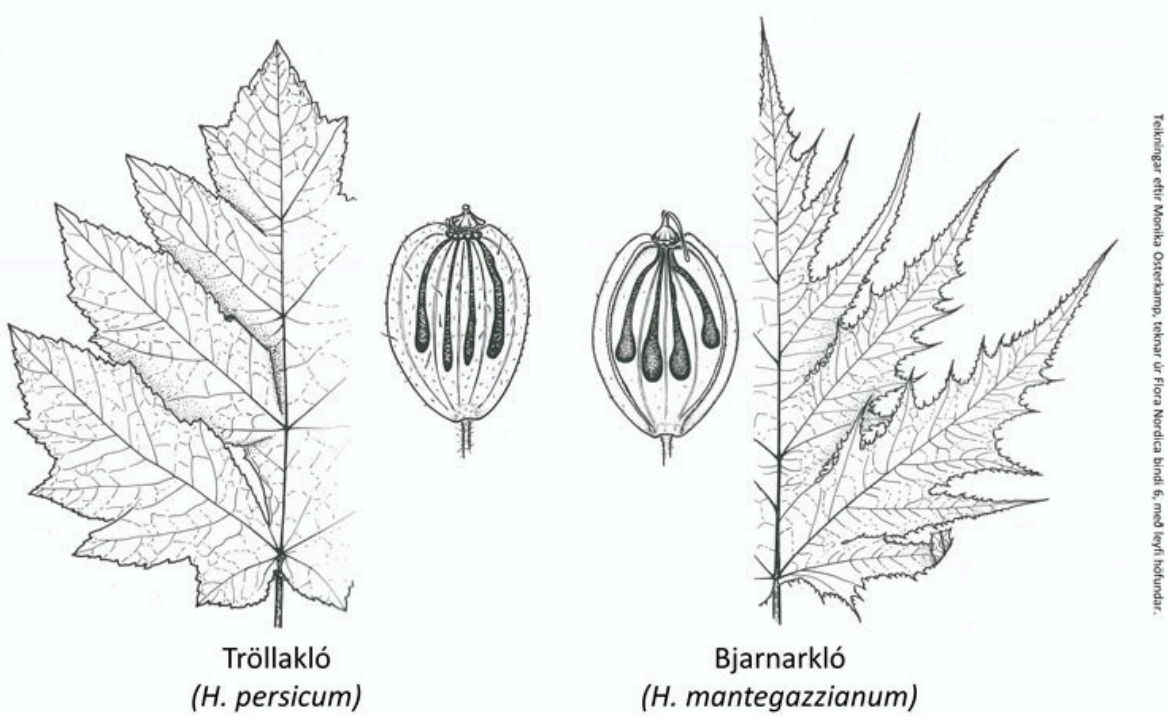


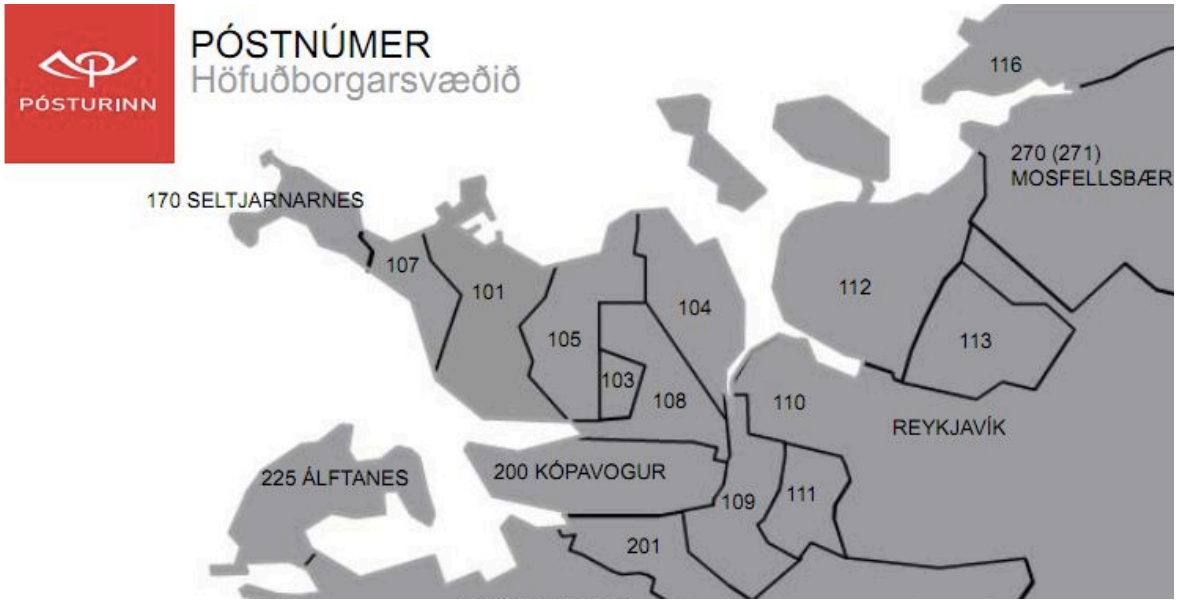
Figure 1.2: ***H. sphondylium.*** (Common Hogweed / Húnakló). *Photo credit: Gemeine Barenklau.*

1.2.2 Mapping hogweed distribution

The distribution of all three hogweed species were mapped with the ArcGIS Collector application and visiting known sites and nearby areas multiple times during the summer of 2017. Data collected was used to evaluate changes in distribution (if any) since the assessment in 2016. Mapping began in May 2017 by scouting all of the streets in Reykjavík with known locations of all three hogweed species, as well as areas nearby where hogweed was suspected to grow. Scouting was conducted by either walking or riding a bicycle about 5 days a week for approximately 7 hours a day. The city of Reykjavík is made up of different boroughs in which all known hogweed sites were visited. Within the city borders, target areas for management were established. Target areas were defined as a high priority area: such as protected wilderness locations, locations nearby school yards, and children´s play areas. It is important to have these priority areas because they present the largest threat to public health and biodiversity of native species. Using this information, a thorough assessment was completed within all of the boroughs of Reykjavík (Figure 1.3), where the presence of all three hogweed species was recorded. Both private and public areas were covered and distributional patterns were evaluated.

The ArcGIS Collector application collected coordinate data, which was then synched to the ArcGIS mapping platform of the City of Reykjavík. When a hogweed species was present, a point would be dropped on the map and color-coded based on the specific species. Overall, the distribution of hogweed species was evaluated for each district in Reykjavík.

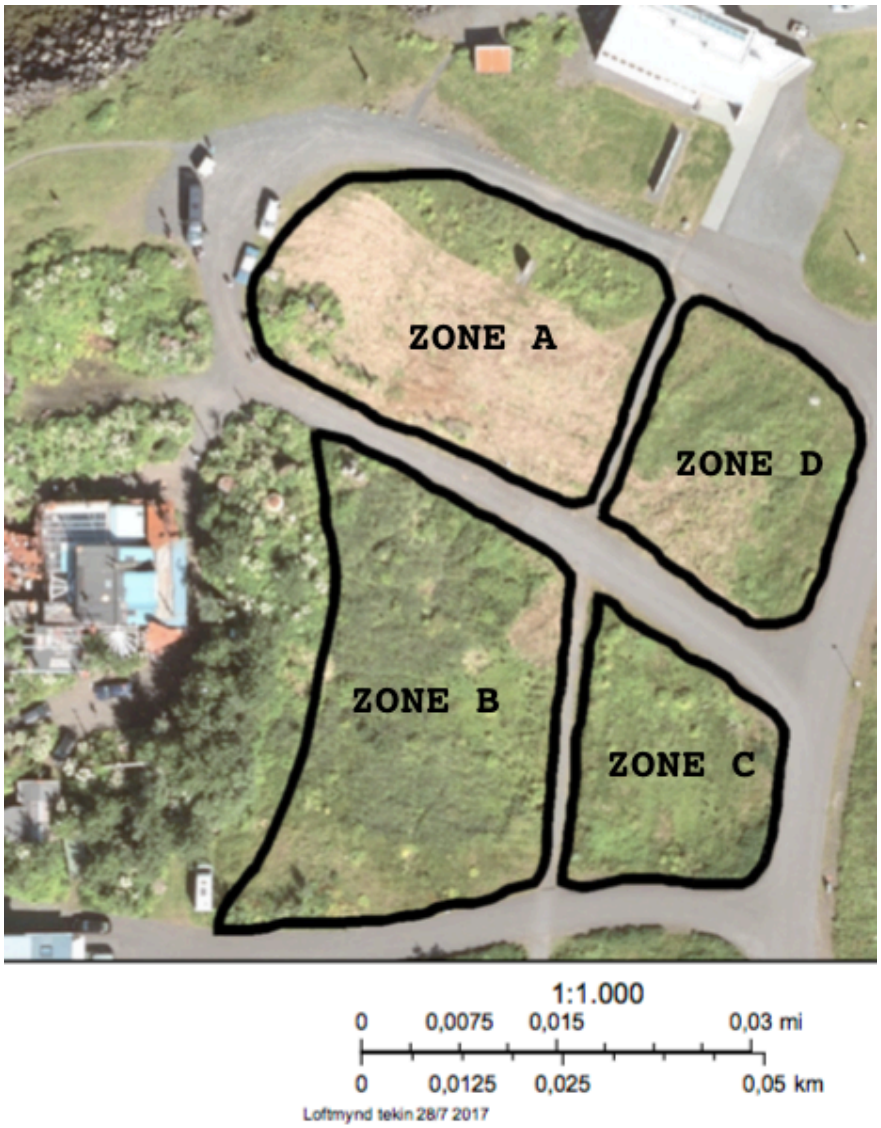
Figure 1.3: Reykjavík districts. Visual of district locations in Reykjavík, Iceland. (*Source: Pósturinn, 2018*).



A focus area in the city, Laugarnes, was selected to investigate the relationship between hogweed density and local plant diversity. Laugarnes is a protected shoreline region located on the Icelandic Nature Conservation Register (Umhverfisstofnun, 2018). The area is highly vegetated and contains an assortment of both native and non-native

species. Many non-native species are found in Laugarnes due to a long history of introduction by the local residents. The reason for choosing Laugarnes as a focus area was because of the field observation of dense growth of giant hogweed plants and other various alien plant species, all of which are either invasive (e.g., Nootka lupin = *Lupinus nootkatensis*) or have shown potential for it (e.g., fireweed = *Chamerion angustifolium*). Plot surveys were conducted in Laugarnes the end of May, where the front grassland field was divided into four zones (A-D; Figure 1.4). In each of these zones, 2 to 3 grid plots measuring 2 x 2 m were randomly placed. Due to the vast size of the giant hogweed stems, 2 x 2 m plots were desired as opposed to a standard 1 x 1 m plot. Each plot was surrounded by at least a 1 m buffer zone. The plots were assessed for plant species richness and percent cover. Plant richness was estimated using classification categories of species level- with the exception of grasses and mosses which were grouped together into one category. Each species category was given a percentage of the area that it covered within the plot, based on a visual observation.

Figure 1.4: Hogweed survey zones in the Laugarnes area in Reykjavík, Iceland. *An aerial photograph derived from Borgarvefsjá / Reykjavíkurborg, captured July 28, 2017.*



In addition to Laugarnes, the habitat types associated with areas where hogweed was growing were characterized to determine if differences occur in habitat conditions and/or plant communities in several survey areas around within the city of Reykjavík. The habitat traits that were observed consisted of the soil type, average climate and rainfall, type of terrain, and urban or wilderness area. The habitat characterization was additionally organized as private land or public land. Although this habitat data was not used for this study, it will aid the City of Reykjavík to assess the impacts of hogweed species on diversity and develop management strategies.

1.3 Results

1.3.1 Distribution of hogweed species in Reykjavík

All three hogweed species were mapped in 11 districts in Reykjavík: which included 53 public land locations and 70 private land locations (Table 1.1). The highest number of identified sites were in districts 101 and 107, which are positioned in the westernmost part of the city and among the oldest residential areas (Figure 1.3). In these districts, hogweed was more common in private gardens than in public locations (Table 1.1). The 107 district is known as Vesturbær and the 101 district is made up of the downtown city area, with not much wilderness space.

The distribution in the 101 district consisted mostly of giant hogweed found within older private gardens in the downtown area. There were 10 locations listed as public land and 23 locations listed as private property. Common hogweed and Persian hogweed were not found in the 101 district, and there was no overlap detected among the three species. The giant hogweed in the 101 district was not widely distributed: a typical site was a private garden with a shaded area. Often, giant hogweed occurred as a few individual plants, but in some cases, there were numerous individuals and the plants had started to spread within and sometimes out of the yard. The giant hogweed was also commonly found to be growing behind garbage bins and under trees. Some of the public locations were along sidewalks, usually quite close to another giant hogweed site in a private garden: which was most likely the source of origin.

In the 107 district, the common hogweed was by far the most common of the three species but a couple of locations did have giant hogweed plants. No Persian hogweed was found in the 107 district. The giant hogweed in the 107 district was found in public playground areas (Faxaskjól), the open area by the sea (Ægissíða), and was also found in private gardens. The common hogweed was found to be extremely widespread in both public and private properties. In particular, the common hogweed was flourishing around schoolyards and playground areas. The common hogweed was growing in large patches and its overall distribution area was quite uniform, showing the highest concentrations in the middle of the area and less dense on the edges where it is spreading. On the other hand, the distribution of giant hogweed was more scattered and random. There were only 2 locations where an overlap between giant and common hogweed was found.

Table 1.1: Hogweed species count in Reykjavík districts. Number of properties (private and/or public) where at least one hogweed species was present are shown.

District Name	District Number	# of Public locations	# of Private locations
Vesturbær	107	11	23
Miðbær	101	10	23
Hlíðar	105	7	5
Háaleiti	103	1	1
Bústaðahverfi	108	3	3
Laugardalur	104	2	6
Seljahverfi	109	3	1
Breiðholt	111	2	2
Árbær	110	5	3
Grafarvogur	112	6	1
Grafarholt	113	3	2
	TOTAL	**53**	**70**

The general distribution of hogweed species in Reykjavík is presented in Figure 1.5, below. Overall, giant hogweed was most prevalent in districts 101 and 105. Common hogweed was most prevalent in district 107; but in other locations it was more sporadic with fewer individual plants. Furthermore, common hogweed has also been found growing in great quantities at Gullinbrú and Hólmsheiði. Common hogweed seems to be the most prevalent of the three species in the city, in regard to the number of individual plants. Giant hogweed is found in the most district localities of Reykjavík. Persian hogweed was not found to be prevalent or highly distributed anywhere at this time.

Figure 1.5: Distribution of *Heracleum* species in western Reykjavík, Iceland in 2017. The location of giant hogweed (green dots), common hogweed (purple dots), and Persian hogweed (yellow dots) are shown. Giant hogweed (red diamonds) and common hogweed (orange diamonds) plants that were eradicated in the Laugarnes area in July and August 2017 are also shown.

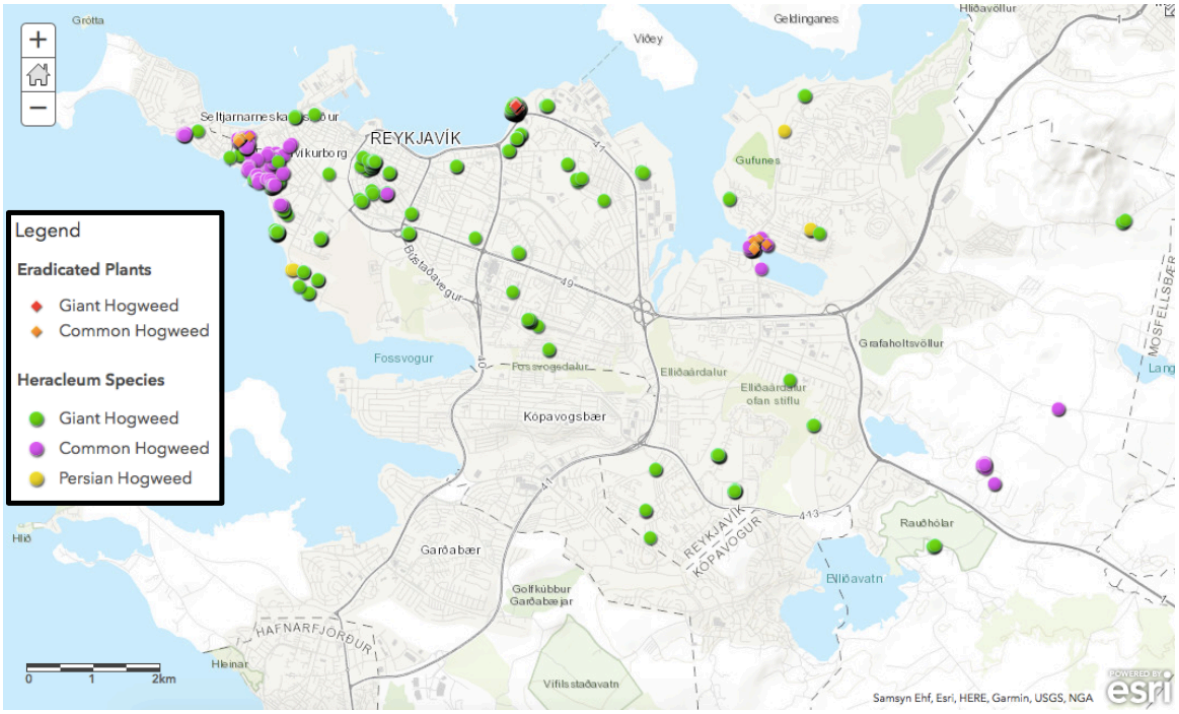
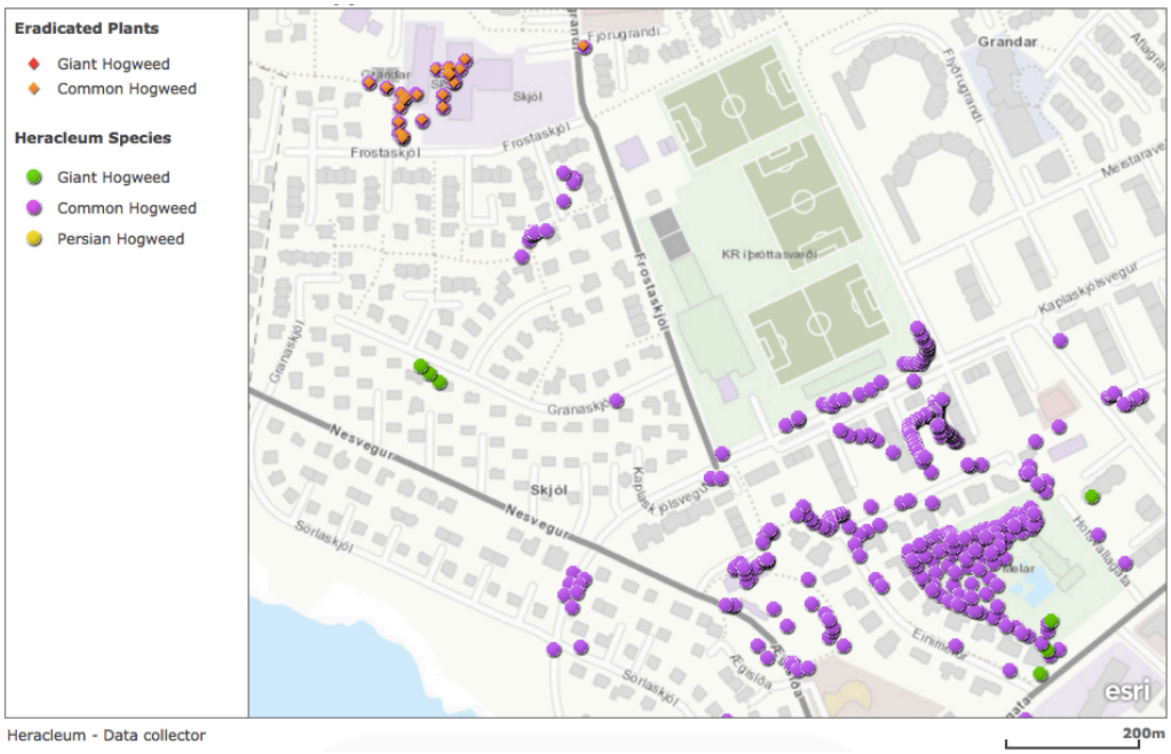


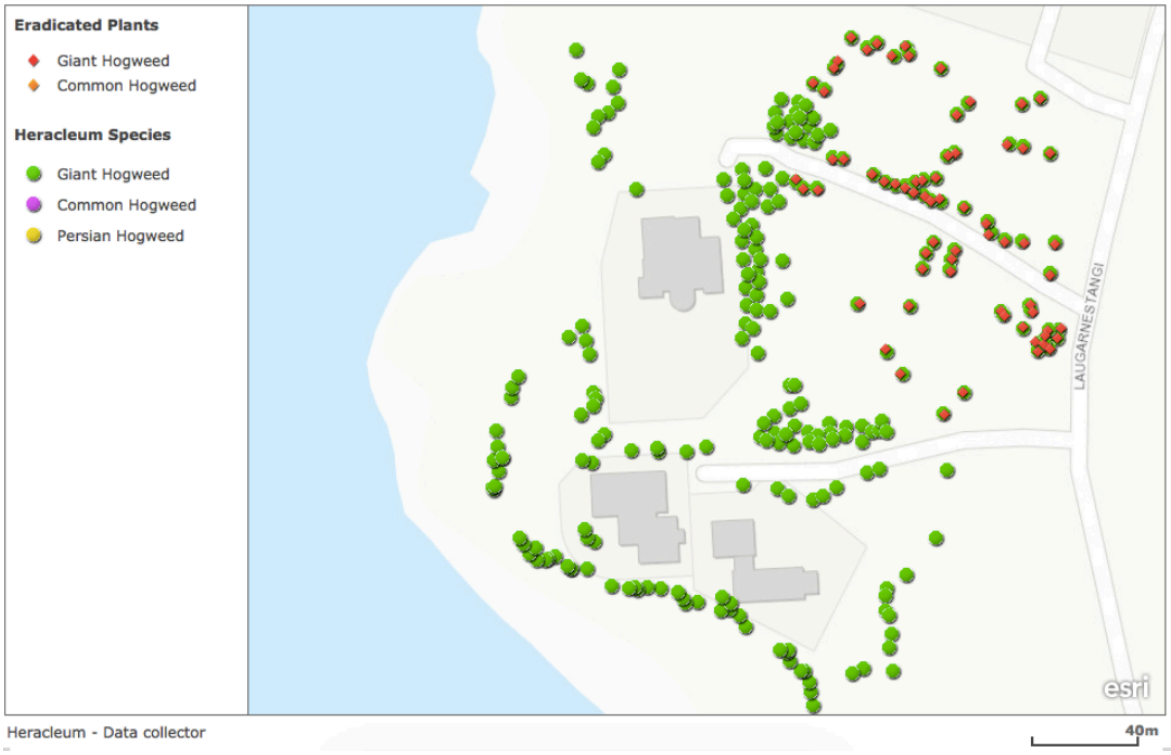
Figure 1.6 below displays the distribution of common hogweed in the 107 district where the species was discovered to be most abundant. The distribution of common hogweed at this location is more of a continuous patch than scattered individual plants. The common hogweed appears to spread more in open spaces such as wilderness areas or parks. Compared to the 2016 survey data, the 2017 assessment shows a significant increase in distribution. In 2017, the city implemented both chemical and manual eradication in this area. The manual eradication was done by cutting the plants and disposing of the umbels in black garbage bags. The sites where eradication efforts were carried out during the study are marked in Figure 1.6 by the orange diamonds. It is important to note that additional eradication efforts were implemented later on that are not included in Figure 1.6, such as a chemical eradication of common hogweed around Vesturbærlaug.

Figure 1.6: Distribution and eradication sites of common hogweed in Vesturbær in 2017. The purple dots represent the locations where common hogweed was found, and the orange diamonds are areas where eradication actions were implemented during time of survey.



The distribution of the giant hogweed population in Laugarnes is highlighted in Figure 1.7. The giant hogweed was mapped and marked with a green circle and the eradication sites are overlapped with a red diamond. An eradication effort was carried out by the City of Reykjavík in June 2017 through manual cutting and mowing, and disposing the umbels in black garbage bags.

Figure 1.7: Distribution and eradication sites of giant hogweed in Laugarnes in 2017. The green dots represent where giant hogweed was present, while the red diamonds indicate the areas where giant hogweed was removed. Note that common hogweed and Persian hogweed were not found in Laugarnes.



1.3.2 Plant diversity in giant hogweed-dominated communities

Laugarnes was divided into 4 zones (Figure 1.4) in which random plots were placed and species richness and plant cover were determined (Tables 1.2-1.5). Overall, 9 plant taxa were found in Zone A and four of them were alien species (Table 1.2). Garden angelica (*Angelica archangelica*) and cow parsley (*Anthriscus sylvestris*) had the highest mean cover. Giant hogweed was the fourth most common plant (20% mean cover). On average, 55% of the plant cover in Zone A was from native plant taxa, while the rest was from alien plant species with cow parsley most prevalent of the alien species.

Table 1.2: Plant community of Zone A in the Laugarnes area. The plant species present and their cover (%) are shown for three survey plots (2 x 2 m) that were randomly placed in Zone A. The surveys were conducted in May 31, 2017.

Plant species	Common name	Plot A1 % cover	Plot A2 % cover	Plot A3 % cover	Average
Angelica archangelica	Garden angelica (Ætihvönn)	40	25	5	23.3
Ranunculus acris	Meadow buttercup (Brennisóley)	10	1	0	3.7
Anthriscus sylvestris	Cow parsley (Skógarkerfill)	10	10	50	23.3
Taraxacum officinale	Common dandelion (Túnfífill)	5	1	0	2
Chamerion angustifolium	Rosebay willowherb (Sigurskúfur)	0	0	0	0
Heracleum mantegazzianum	Giant hogweed (Bjarnarkló)	0	15	45	20
Poaceae	Grasses (3+ types)	30	37	0	22.3
Alchemilla mollis	Lady´s mantle (Garðamaríustakkur)	0	1	0	
Lupinus nootkatensis	Nootka lupin (Alaskalúpína)	0	5	0	1.7
Bryophyta	Mosses + other species	5	5	0	3.3
Myrrhis odorata	Sweet cicely (Spánarkerfill)	0	0	0	0
Cirsium arvense	Creeping thistle (Þistill)	0	0	0	0

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In contrast, 10 plant taxa were present in Zone B and giant hogweed was the most common species (23% mean cover) (Table 1.3). Cow parsley was the third most common plant in the zone (13% mean cover). Both giant hogweed and cow parsley were the most prominent alien species here.

Table 1.3: Plant community of Zone B in the Laugarnes area. The plant species present and their cover (%) are shown for three survey plots (2 x 2 m) that were randomly placed in Zone B. Surveys were conducted in May 31, 2017.

Plant species	Common name	Plot B1 % cover	Plot B2 % cover	Plot B3 % cover	Average
Angelica archangelica	Garden angelica(Ætihvönn)	10	0	0	3.3
Ranunculus acris	Meadow buttercup (Brennisóley)	10	20	20	16.7
Anthriscus sylvestris	Cow parsley (Skógarkerfill)	40	0	0	13.3
Taraxacum officinale	Common dandelion (Túnfífill)	2	35	3	13.3
Chamerion angustifolium	Rosebay willowherb (Sigurskúfur)	0	5	0	1.7
Heracleum mantegazzianum	Giant hogweed (Bjarnarkló)	28	15	30	24.3
Poaceae	Grasses (3+ types)	0	15	35	16.7
Alchemilla mollis	Lady´s mantle (Garðamaríustakkur)	0	0	0	0
Lupinus nootkatensis	Nootka lupi*n* (Alaskalúpína)	0	0	0	0
Bryophyta	Mosses + other species	0	0	7	2.3
Myrrhis odorata	Sweet cicely (Spánarkerfill)	0	0	5	1.7
Cirsium arvense	Creeping thistle (Þistill)	10	10	0	6.7

Zone C had 10 plant taxa, of which half were alien species, and on average Nootka lupin (*Lupinus nootkatensis*) had the highest plant cover encountered (Table 1.4). but was only found in one plot of the two evaluated. Overall, Zone C was the only zone dominated by alien species (52% mean cover). Giant hogweed was not nearly as prevalent in this zone.

Table 1.4: Plant community of Zone C in the Laugarnes area. The plant species present and their cover (%) are shown for two survey plots (2 x 2 m) that were randomly placed in Zone C. Surveys were conducted in May 31, 2017.

Plant species	Common name	Plot C1 % cover	Plot C2 % cover	Average
Angelica archangelica	Garden angelica(Ætihvönn)	20	15	17.5
Ranunculus acris	Meadow buttercup (Brennisóley)	0	25	12.5
Anthriscus sylvestris	Cow parsley (Skógarkerfill)	15	0	7.5
Taraxacum officinale	Common dandelion (Túnfífill)	5	5	5
Chamerion angustifolium	Rosebay willowherb (Sigurskúfur)	0	5	2.5
Heracleum mantegazzianum	Giant hogweed (Bjarnarkló)	0	10	5
Poaceae	Grasses (3+ types)	10	15	12.5
Alchemilla mollis	Lady´s mantle (Garðamaríustakkur)	0	0	0
Lupinus nootkatensis	Nootka lupi*n* (Alaskalúpína)	45	0	22.5
Bryophyta	Mosses + other species	5	0	2.5
Myrrhis odorata	Sweet cicely (Spánarkerfill)	0	25	12.5
Cirsium arvense	Creeping thistle (Þistill)	0	0	0

Zone D had the lowest richness, only 6 plant taxa were found (Table 1.5). Grasses and meadow buttercup were the most common plants and both were native taxa. Giant hogweed and sweet cicely were the only alien plant species in this zone. Alien plants covered on average 23% of Zone C, which was the lowest coverage of alien species in all the zones.

Based on average plant cover only Zone C has more alien plant species than native plant taxa; in the other zones, native plant taxa are >50% of plant cover.

Table 1.5: Plant community of Zone D in the Laugarnes area. The plant species present and their cover (%) are shown for two survey plots (2 x 2 m) that were randomly placed in Zone D. Surveys were conducted in May 31, 2017.

Plant species	Common name	Plot D1 % cover	Plot D2 % cover	Average
Angelica archangelica	Garden angelica(Ætihvönn)	0	0	0
Ranunculus acris	Meadow buttercup (Brennisóley)	15	15	15
Anthriscus sylvestris	Cow parsley (Skógarkerfill)	0	0	0
Taraxacum officinale	Common dandelion (Túnfífill)	5	10	7.5
Chamerion angustifolium	Rosebay willowherb (Sigurskúfur)	0	0	0
Heracleum mantegazzianum	Giant hogweed (Bjarnarkló)	15	15	15
Poaceae	Grasses (3+ types)	35	60	47.5
Alchemilla mollis	Lady´s mantle (Garðamaríustakkur)	0	0	0
Lupinus nootkatensis	Nootka lupi*n* (Alaskalúpína)	0	0	0
Bryophyta	Mosses + other species	15	0	7.5
Myrrhis odorata	Sweet cicely (Spánarkerfill)	15	0	7.5
Cirsium arvense	Creeping thistle (Þistill)	0	0	0

The Simpson's biodiversity index for the zones ranged from 0.68 to 0.78, suggesting similar plant biodiversity among the zones (Table 1.6). Zone A had on average the lowest biodiversity value, while Zone C the highest. Overall, these results appear to indicate a relatively high plant biodiversity in the Laugarnes area- however, the species richness is relatively low and only the plant over is similar amongst the species (similar evenness). A greater number of plots need to be surveyed in the future to further validate these results. The total average biodiversity index for all zones is 0.73.

Table 1.6: Simpson Biodiversity Index of Laugarnes Zones.

	Zone A	Zone B	Zone C	Zone D	All Zones
Plot 1	0.73	0.74	0.73	0.79	
Plot 2	0.77	0.79	0.82	0.59	
Plot 3	0.55	0.75	N/A	N/A	
Average	**0.68**	**0.76**	**0.78**	**0.69**	**0.73**

The plot surveys in the Laugarnes area documented six alien plant species and six native plant species (Table 1.7) being most prominent. Of the 12 species (or taxa groups) found within the Laugarnes plots, three are native and less common species, three are native abundant species, two are alien and less common species, and four are alien abundant species. When viewing aerial photographs, it can be approximated that 30% of soil space in Laugarnes is covered by an alien species. Furthermore, all of the prominent alien species are invasive species. Of the three hogweed species in this study, only giant hogweed was found in the Laugarnes experimental site. Within one plot, the coverage of giant hogweed was highest at 45% in Zone A, Plot 3- as seen in Table 1.2 above. The species and taxa most commonly associated with giant hogweed are garden angelica, grasses, and Nootka lupin.

Table 1.7: Alien and native species present in Laugarnes area.

Native dominant	Native less common	Alien dominant	Alien less common
Garden Angelica[4] Meadow Buttercup[5] Grasses[6]	Common Dandelion[1] Lady´s Mantle[2] Mosses[3]	Giant Hogweed[9] Cow Parsley[10] Nootka Lupin[11] Sweet Cicely[12]	Creeping Thistle[7] Rosebay Willowherb[8]

[1]Taraxacum officinale, [2]Alchemilla mollis, [3]Bryophyta, [4]Angelica archangelica, [5]Ranunculus acris, [6]Poaceae, [7]Cirsium arvense, [8]Chamerion angustifolium, [9]Heracleum mantegazzianum, [10]Anthriscus sylvestris, [11]Lupinus nootkatensis, [12]Myrrhis odorata.

1.4 Discussion

The overall distribution of hogweed is increasing throughout Reykjavík. Plants are spreading into new areas in close proximity to existing populations from previous years. In particular, giant hogweed is becoming a prevalent species: often having a large biomass and being the most prominent plant species where it is present, out-competing other species for soil space due to its massive size. This is of high concern because of the hazard

to public health, loss of biodiversity, and the difficulty and costly process of eradicating the plants once they have established.

Similarities were found in the areas where hogweed species are present. All three hogweed species grow well in urban areas and in wilderness areas, as was seen by the giant hogweed population in Laugarnes and the common hogweed populations in Vesturbær and Hólmsheiði (refer to Figure 1.5). However, some differences in distribution were seen among the hogweed. For example, giant hogweed is found in more vegetated areas and in private gardens. In contrast, common hogweed is typically found in areas that are more open and Persian hogweed is presently found in 1 or 2 private gardens in Reykjavík and does not seem to be spreading at this time. Based on the mapping and surveys from previous years, each hogweed species appears to be spreading at different rates. Giant hogweed and common hogweed are spreading more rapidly than Persian hogweed. Common hogweed seems to be spreading the fastest and appears to be the most abundant of the three hogweed species. Common hogweed is listed as a casual alien plant in Iceland (Wasowicz et al., 2013). According to Pyšek et al. (2004), a casual alien plant is defined as an alien plant that "may flourish and even reproduce occasionally outside cultivation in an area, but that eventually dies out because they do not form self-replacing populations, and rely on repeated introductions for their persistence; while naturalized plants are alien plants that sustain self-replacing populations for at least ten years without a direct intervention by people (or in spite of human intervention) by recruitment from seed or ramets (tillers, tubers, bulbs, fragments, etc.) capable of independent growth" (Pyšek et al., 2004). Given this data, common hogweed may be becoming a naturalized plant which warrants additional research in order to confirm this. Common hogweed is a sudden and unexpected threat in Iceland, and seems to be having a similar rapid growth in both urban areas such as Vesturbær and wilderness areas in Reykjavik. The latter is of great concern, as common hogweed may threaten plant biodiversity in other wilderness areas outside the city in the future. If left unmanaged, common hogweed may become widespread and abundant throughout Reykjavík and other wilderness areas.

Persian hogweed is not currently considered a threat in Reykjavík at this time, but it should continue to be monitored along with the other hogweed species so that we can learn more about its distribution patterns and observe if it is spreading. In northern Iceland, Persian hogweed has become naturalized and is considered a "potential invasive species" (Wasowicz et al., 2013). However, The City of Reykjavík can avoid a potential problem given the growth of Persian hogweed in northern Iceland by monitoring the growth of the species through early detection and through rapid and complete eradication. In addition, this can highlight the need for public outreach and awareness so that the community can avoid growing the potential invasive species. Currently, Persian hogweed is found in only 2 private gardens: and the homeowners are aware of the plant´s physiology and were given eradication and safety instructions during the summer of 2017. Persian hogweed was not found on any public land in Reykjavík.

The City of Reykjavík would benefit in developing a management plan to monitor and manage the spread of hogweed. A key component of the plan is to establish and target priority areas. Priority areas include wilderness areas of importance, schoolyards and playgrounds, and other areas where hogweed is growing abundantly. This will prevent the hogweed from displacing native and rare Icelandic plants, as well as reduce the risk of people coming into contact with the phototoxic sap of hogweed.

Hogweed is present in both public land areas (53 sites) and private properties (70 sites) in Reykjavík, which highlights the importance of public outreach in managing invasive species in urban areas. By spreading awareness through information sheets,

various media outlets, and informing gardeners, public support and participation in managing hogweed species and other invasive species in Reykjavík can be fostered. Research indicates that increasing public awareness increases the public support for managing an invasive species (Novoa et al., 2017): in which they aimed to compare if landscape type (urban vs non-urban) influenced public awareness about management of an invasive species; and then assessed the public awareness factor to see if it correlated with public support for management (Novoa et al., 2017). The study found that providing a limited amount of information noticeably helped to bring attention to awareness and support- but it is unclear at this time if it is beneficial for long-term management as a genuine change- thus, further and more extensive studies are recommended (Novoa et al., 2017). This highlights the need for continued surveying and documentation of facts throughout years to come. Another finding of Novoa´s is the importance of identifying different stakeholders between urban and non-urban areas to socially support invasive species management (Novoa et al., 2017). In Reykjavík, it would be beneficial to assess whether there is a difference of perception between residents that live in a downtown area compared to those who live more in an open, wilderness area. In the downtown urban area, the possibility of the species spreading is less due to barriers such as sidewalks or roads; whereas in a wilderness area, the species distribution could spread rapidly because there are no barriers. In addition, the presence of species is more of a health issue in the downtown residential spots than in the wilderness areas: due to the proximity of the species growing near playgrounds, schools, and private gardens. Furthermore, it would be interesting to find different approaches in involving the community and gaining support. In addition, introducing the topic to younger generations or in schools could be beneficial in the long term as far as spreading public awareness on an invasive and potentially harmful species.

To evaluate the impact of the hogweed species, the 2016 areas where eradication and control were implemented were visited for a one year post-treatment assessment to see if the plants were still present in these areas; and if they had spread or cultivated the land more heavily. This helped to determine if the control or eradication methods of 2016 were successful and if they should be used again- or if new methods and additional research is needed. The evaluation indicated that there was not enough data from 2016 to compare; which emphasized the need for further future planning and assessment. However, giant hogweed has little or no presence in the few manual eradication sites from 2016 that were visited in 2017- indicating some eradication success. Throughout July and August of 2017, a combined chemical and manual eradication of common hogweed was completed in various sites within 107 Reykjavík: including all school yards and playgrounds. In addition, plants were eradicated along public streets and near the swimming pool. Chemical eradication was also implemented in the 107 district.

In the life cycle of a plant, the most vulnerable stage of growth is during its seedling stage. Young seedlings are most at risk for mortality due to the threat of herbivores and various pathogens (Harper, 1977). The seedlings of hogweed species are likely to thrive and grow well in Iceland as the country has relatively few insect herbivores and pathogens compared to other regions, and also insect herbivore specialists are more common in the native range of giant hogweed and other invasive species than in their introduced range (Hansen et al., 2007; Halldórsson et al., 2013). Furthermore, giant hogweed seedlings are well adapted to the cool climatic conditions in its native range (Russia and Georgia), and therefore can have a higher chance of survival in frost. "Early germination allows the seedlings to cover patches of open ground and reach a sufficiently advanced stage before

they are overgrown by adult plants of giant hogweed or other species" (Harper, 1977). Given this information, it is likely that the seeds and plants of giant hogweed and other hogweed species are suited to the environmental conditions in Iceland.

Overall, this study is important because urban areas can be hot spots for invasive species. Management is key to protect and enhance biodiversity, and promote the health of all ecosystem services in cities and in wilderness areas. The impacts of an invasive alien species can potentially linger even after eradication efforts; and once an ecosystem has changed, it may never go back to its original, natural state. Tekiela and Barney (2017) studied the accumulation and loss, or legacy effects, of impacts following the establishment and removal of an invasive species. They found that ecosystems respond to changes in the abundance of an invasive species and when it is removed, the resident plant community could have long-term changes, leaving behind an invasion shadow (Tekiela & Barey, 2017). This study highlights the importance of preventing invasions in urban and wilderness areas. This is especially crucial in a protected or wilderness area that contains delicate and vulnerable native flora. Thus, it is important to detect and manage the presence of an alien invasive species in the early stages of its invasion before it becomes widespread: requiring costly and time-consuming efforts.

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1.5 Conclusions

This research provided a much-needed assessment of the distribution and management efforts of the potentially invasive hogweed (*Heracleum* species) in Reykjavík, Iceland. The mapping data indicated that giant hogweed, common hogweed and Persian hogweed are distributed in different parts of the city. Common hogweed and giant hogweed are heavily invading certain areas of the city (Vesturbær and Laugernes), and seem to have a negative impact on the native plant community. Most of the giant hogweed invasions are confined in private gardens; while most of the common hogweed invasions are evenly distributed on both private and public land. The common hogweed has shown to tolerate more areas in Reykjavík, and has presented with more plasticity than giant hogweed and Persian hogweed. Given the new discovery of the common hogweed invasion in Reykjavík and that this plant is newly identified as an invasive species in the city: it is important to further assess and monitor the distribution patterns of this species and sites where it has been managed.

Follow-up assessments of the research and control efforts conducted in 2017 are recommended to evaluate current and future management options. In addition, monitoring of known areas where hogweed is present is crucial to protect priority areas and understand the growth and spread of these species. A management plan for hogweed that is both cost-effective and successful can be developed for Reykjavík. This plan should include public outreach; consistent monitoring of the distribution and impacts of hogweed; early detection and eradication actions; targeted control in priority areas; and research on the recovery of managed areas. Lastly, studying the surrounding plant communities that are present where hogweed occurs is crucial to understand invasion rates, impacts, potential dispersal pathways, and facilitation of other invasive plants found in the same proximity. Moreover, changes in plant biodiversity should be monitored as they may help detect new invasions.

2. Management of Hogweed

2.1 Introduction

When confronting an invasive species in an urban area, many obstacles come into consideration. Many studies have demonstrated that cities are hotspots of invasions, particularly for plants (van Ham et al., 2013). For example, in a city or highly populated area, many pathways and vectors can increase the risk of invasion by an alien or non-native species. Some examples of vectors or possible pathways can include the introduction and establishment of ornamental plants, trade of pets, ships docking, and having exotic botanical gardens and zoos. The urban environment is often characterized by high levels of disturbance, transportation, and has a high environmental heterogeneity. This highlights its role in biological invasions (van Ham et al., 2013). Human settlements are often the point of origin of many invasive species; which spread into adjacent landscapes along transport corridors such as railways, roads, or waterways; and in many cases, eventually invading natural wilderness areas (Alston & Richardson, 2006; van Ham et al., 2013; McLean et al., 2017).

Climate change is linked to invasive species in both urban and rural areas. In addition, climate change can "alter natural species abundance and distribution or favor invasive species, which in turn can alter ecosystem dynamics and the provisioning of ecosystem services" (Ort & Ainsworth, 2012). The Intergovernmental Panel on Climate Change (2018) predicts a temperature rise of 1-3 degrees Celsius (or 1.8-5.4 degrees Fahrenheit) over the next century. This can affect the growth and spread of an invasive species if they are better adapted to the environment than the native species. Therefore, invasive species are more likely to be "successful and abundant, whereas many native species are rare" (Hellmann et al, 2008).

Hogweed species (*Heracleum)* have proven to be problematic invaders in many places in the world. The purpose of this literature review is to analyze management methods of hogweed species in other countries and then recommend management guidelines for the control of the species in Reykjavík, Iceland. Research priorities will be determined in this chapter.

2.2 Management of hogweed in other countries

Eradication and control methods from other countries can be evaluated to assist in the regulation or removal of hogweed (*Heracleum* species) in Iceland. Several techniques to eradicate and control invasive plants exist; and vary depending on the environment and the target species. Overall, three general categories cover most invasive plant management actions: mechanical control methods, biological control methods, and chemical control methods (Mattrick, 2010). Mechanical control methods include pulling and digging plants, plant suffocation, and cutting or mowing plants; and they are usually implemented first when evaluating a way to remove invasive plants. However, mechanical control removal methods involve a lot of manual labor and they can cause extra disturbance to the target site; leading to additional land degradation (Mattrick, 2010). For example, in Iceland,

Nootka lupin (*Lupinus nootkatensis)* is another known invasive alien plant that is under management and control. The most common and desired form of eradication of Nootka lupin in Iceland is via mechanical control; but it can lead to further land degradation if not continued and monitored for several years due to regeneration and/or limited resources or funding to continue. Herbicides are the most common implementation of chemical control methods in which a poison is applied to kill the plants and inhibit further growth through foliar applications or various cut stem treatments. An example of an herbicide being used to control another invasive alien plant (Nootka lupin) in Iceland is from 2010, when a municipality (Stykkishólmur) used both mechanical (cutting) and glyphosate herbicide to eradicate the species in a target area. The results show that herbicide alongside cutting was successful (Svavarsdóttir et al., 2016). Biological control methods involve using control agents such as insects or pests to reduce the spread and distribution of invasive plants. Kettenring and Adams (2011) assessed the use and efficiency of different invasive plant control efforts. Over 59% of the assessed efforts were herbicide treatments (glyphosate being the most popular herbicide representing 42% of the studies). Mechanical control was the second most common method, where 34% of the studies used cutting techniques which included mowing, weed whipping, string trimming, or using a chain-saw. In addition, 24% of the studies used burning to control invasive plants. Furthermore, only 33% of all studies assessed attempted restoration to reestablish the native plant communities after controlling invasive plants (Kettenring & Adams, 2011). Similarly, the majority of studies (71%) did not take into consideration the economic cost of invasive plant control (Kettenring & Adams, 2011). However, nearly 60% of the studies reported that repeated, long-term monitoring efforts are mandatory to control invasive plant species; this especially applies to herbicide or hand-pulling methods.

In the Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden) the presence of large hogweed (*Heracleum* species) has been known since the first third of the 19th century: however, it was not until the mid 20th century that researchers realized that there was more than one species of hogweed (Pyšek et al., 2007). The main mechanism of spread of giant hogweed appears to be via gardening as an ornamental plant. (Jahodová et al., 2007). This is important to recognize in regard to the management options for Iceland, where giant hogweed is prevalent in many private gardens. By comparing management and control options of giant hogweed and other hogweed species to other Nordic countries with similar climates, it enables Iceland to identify the methods that are effective and cost-efficient.

For example, Tiley and Philp (1997) studied the effect of manually cutting giant hogweed in Scotland at different root depths and stem heights on regeneration. They observed that cutting the tap root at 15 centimeters below the ground killed the plants in the vegetative or reproductive stage- resulting in none of the plants regenerating or producing any flowers. Additionally, they found that cutting the plants 5 cm below the soil surface or at the ground level allowed regrowth of shoots from axillary buds below the ground (Tiley and Philp, 1997). This study also revealed that the pattern of regeneration of flowering giant hogweed plants depends on the type of treatment. Plants that were cut to ground level regenerate from the stem base; while those with a stem or partial stem, mostly branched and produced new flowering shoots from leaf nodes between the petioles and the stem (Tiley and Philp, 1997, 2000; Otte and Franke, 1998; Pyšek et al., 2007).

Research in the Czech Republic suggests that "cutting plants to ground level may be less effective in terms of reduction in fruit numbers than removing the umbels and leaving the stems" (Pyšek et al., 2007). The former treatment yielded more than twice as much regeneration, especially when flowers and leaves were removed. This pattern shows that

regeneration of the plant resulted in a reduced fecundity. By cutting the plants, fruit numbers will be decreased. Increased regeneration that comes from cutting the plants to ground level can potentially lead to seed production if the plant goes into a panic state where it can tap into nutrient reserves in the root system (Otte & Franke, 1998). By cutting the umbels instead, fruit numbers will be decreased. Both regeneration and fruit production need to be considered when deciding on control methods in Reykjavík, Iceland: especially in the Laugarnes area where giant hogweed grows very densely.

Otte and Franke (1998) treated plants by cutting twice during the course of the growing season in Central Europe. They found that the new umbels produced by the post-treatment regrowth were also removed during the second cutting treatment. In addition, if the umbels produced by regrowth were removed, then no fruits would be produced during that growing season. This study indicates that the second cutting treatment will likely only be effective if applied later when the new umbels are starting to fruit; and "if the branches bearing regenerating flowering umbels are cut too early, regeneration will continue" (Otte and Franke, 1998). The control efforts implemented in the Laugarnes area in 2017 corroborate the findings from Otte and Franke (1998). Cutting and disposing of the umbels during the flowering stage of growth presented to be a very efficient form of control and eradication although a very arduous task; however, post-treatment monitoring is needed to assess the long-term effectiveness of this method. Moreover, the timing of control is crucial for managing and preventing any regeneration of giant hogweed plants.

If the removed umbels are left behind at the eradication site, they will produce viable seeds due to post-treatment fruit ripening (Nielson et al., 2005). Therefore, it is crucial to properly dispose of the umbels. Pyšek and colleagues (2007) show that "85% of terminal umbels cut off at the beginning of fruit formation produce some fruits that are less and of lower quality" (Pyšek et al., 2007). Hence, giant hogweed plants can survive many control efforts due to their high regeneration capacity. Five key guidelines for controlling giant hogweed (Table 2.1) were developed based on the research of Pyšek et al. (2007) and others.

Table 2.1: General guidelines to control giant hogweed (*Heracleum mantegazzianum).* These guidelines are from the research of Pyšek et al. (2007) and others cited below.

1. The only treatment that immediately kills plants of giant hogweed is cutting the tap root 15 cm below ground. Any treatment that does not kill the plants, such as cutting at ground level, always results in a proportion of treated plants regenerating (Pyšek et al., 1995, 2007; Tiley & Philp, 1997; Caffrey, 1999).
2. Whatever the strategy for mechanical control, the life stage of the plants targeted for control is critical. Above-ground cutting of the vegetative (rosette) stage will not kill the plants, but extends their life span by postponing the time of flowering. Vegetative plants can only be killed by cutting the root. In the case of flowering plants, it is not necessary to cut the root below the soil surface as once flowering is initiated these plants will not survive until the next year. Therefore, the best strategy is to kill plants at the rosette stage by cutting their roots and preventing those at the flowering stage from producing fruits. Alternatively, if a long-term program is feasible, only flowering plants need to be targeted until the population is depleted (Pyšek et al., 2007; Pergl et al., 2007).
3. Timing of the treatment is crucial. If carried out too early, plants will regenerate to a high level. Removal of umbels is effective if carried out at the peak of flowering or at the beginning of fruit formation. Subsequent cutting of regenerated flowering umbels, as they emerge, prevents plants from producing fruit. Removal of leaf rosette does not increase the effect of this treatment; there is some evidence that cutting flowering plants at ground level is less efficient than removing flowers and leaves from the stems (Pyšek et al., 2007).
4. Cut umbels must be removed from the site. Even umbels cut at late flowering or early fruiting are able to produce viable seeds and thus should be collected and destroyed (burnt). Cutting whole flowering stems and leaving them at a site is not recommended (Pyšek et al., 2007).
5. Giant hogweed has extraordinary fecundity. Given this fecundity, even a severe reduction in the number of fruits produced by regenerating plants, relative to the control, still results in large quantities of fruit in absolute numbers. More importantly, these seeds are generally of a good quality, in terms of size and viability (see Perglová et al., 2006; Perglová et al., 2007; Pyšek et al., 2007).

Table 2.1 Source: Pyšek, P., Perglová, I., Krinke, L., Jarošik, V., Pergl, J., Moravcová, L. (2007). Regeneration ability of Heracleum mantegazzianum and implications for control. In: Pyšek P., Cock, M. J. W., Nentwig, W. & Ravn H. P. (eds.), Ecology and Management of Giant Hogweed (Heracleum mantegazzianum). CAB International, Wallingford.

The general guidelines to control giant hogweed (Table 2.1) are also applicable to Iceland. The first guideline highlights that to kill giant hogweed plants, they must be cut at least 15 cm below the ground level. The second guideline shows that the mechanical control method must pay close attention to the growth and life stage of the plant at the time of control in order to kill giant hogweed plants and prevent seed production. The third guideline emphasizes that timing in eradication and control is crucial and will not be effective if carried out too early or too late. The fourth guideline highlights the importance of removing and properly disposing the umbels and stems from the eradication site. Lastly, the final guideline underscores the large quantities of fruits that giant hogweed produces, even from regenerating plants.

In regard to Persian and common hogweed, there does not seem to be much information on control methods. Given what is known about the life history of common and Persian hogweed: the guidelines for giant hogweed above are recommended to be applicable for all of the *Heracleum* species in Reykjavík, Iceland. Methods may need to be tested to determine what is most effective for the distribution control of Persian and common hogweed. Common hogweed is presenting with a high fecundity in Reykjavík and has been found to create flowers very rapidly, vastly increasing the dispersal ability.

2.3 Management recommendations for Iceland

Establishing clear management and research goals and priorities is vital for managing hogweed and other invasive species. One essential component of management is continuous evaluation of strategies and actions to ensure the success of control efforts and the restoration of managed areas (McDonald et al., 2016). Both resource managers and researchers need to assess if the management plan is being implemented as intended, the management goals are being achieved, the time and spatial scales are appropriate, and the plan is realistic and cost effective (Kettenring & Adams 2011). Although there is no single strategy that will solve entirely an invasive species problem, a combination of strategies will work to minimize it (FICMNEW, 2003).

Continuous evaluation of management actions should be carried out by monitoring the distribution of hogweed and the response of plant communities on a yearly basis. This will also promote early detection of new hogweed populations, as well as the development of rapid response strategies for populations in high priority areas. In addition, record keeping of expenses such as personnel, equipment, implementation of control efforts, among others, is important for a cost evaluation of the management plan. Similarly, documenting weaknesses, strengths, failures and successes of control methods are essential to adapt the management plan as needed. All this information will help identify the best and cost -effective actions to manage hogweed in Iceland. Kettering et al. (2011) found that most studies on invasive plant control were not followed up with regular, scheduled monitoring efforts: often leading to re-invasion or establishment of invasive species. Therefore, monitoring and assessing the remaining plant communities will help determine if additional control efforts and restoration actions are needed.

The timing in the eradication and control methods of hogweed species is crucial, especially when considering management options for Iceland. All of the hogweed species should be mapped at least every other year to assess and document the distribution and locations. Based on my findings in Chapter 1 and considering the guidelines in Table 2.1,

giant hogweed in particular should be cut at least 15 cm below the ground surface at an appropriate time, and the cut umbels must be removed from the site and properly disposed. Common hogweed and Persian hogweed should also follow these recommended guidelines for effective control and eradication.

Landfill or dump sites should also be monitored for hogweed and other invasive species. This can be done by assessing plant species in known dump sites, including those mapped in 2017 where hogweed was detected. Alien species are a frequent find on landfill sites; and having a ratio of native species to alien species on these sites can be a very helpful indicator of ecosystem richness (Rahman et al., 2013) and also identify potential invaders.

The chemical *Dicotex* was applied to the common hogweed plants growing in the Vesturbær public land locations. After the chemical was applied, manual eradication was implemented by cutting the umbels of the panic plants that emerged as a response to the chemical eradication. The umbels were removed from the area and disposed of in a black garbage bag in order to prevent the seeds from cultivating. These areas were continuously monitored during the eradication process. Overall, the eradication that occurred was minimal and random- but it is important to monitor and analyze these efforts in the future to evaluate their effectiveness.

A manual eradication was implemented in Laugarnes on Friday, July 21, 2017. Equipment used included personal protective equipment, shovels, saws, clippers, and a mower. With this equipment, manual eradication was conducted by cutting and mowing the stems of giant hogweed plants. A team of approximately 10 workers from Reykjavíkurborg´s garden center used these tools to manually eradicate a lot of the giant hogweed plants in Zones A, B, C, and D. All of the umbels were placed into a black garbage bag to prevent any opportunity for the seeds to develop and spread in the location. The umbels were also cut in the surrounding public land areas of the Laugarnes plot and disposed accordingly. An oversight worth mentioning is that we did not do a control grid plot at Laugarnes- which would have been an area outside of where we know the Giant Hogweed is growing, in order to get a grasp of how the biodiversity should be of an area that has not been impacted by the species. It is recommended to do a control grid plot in the next assessment.

An evaluation of control methods based on field data, such as manual eradication vs. chemical eradication, would be beneficial to compare efficacy among hogweed species and various habitats (e.g., urban-wilderness gradient). The surrounding plant communities in hot spot areas, such as Laugarnes, should be studied and monitored to determine if hogweed is negatively impacting the growth and distribution of native plants in the area. Other key areas to monitor include schoolyards and playgrounds in Vesturbær, where common hogweed was found in the 2017 and poses health risks due of its phototoxic sap. The wilderness areas near Hólmsheiði is another area to track, as common and giant hogweed were present in Hólmsheiði in sparsely vegetated sites prone to seed dispersal and further colonization by hogweed.

Public outreach and education on hogweed is an important management objective. In the case of Reykjavík, a community awareness education system can be organized to promote public awareness about hogweed, highlighting their threats to biodiversity and human health. Various social media outlets (Facebook, twitter, snapchat) and other news forums (radio, podcasts, television, newspapers) can be used, as well as distributing fact sheets. For example, the City of Reykjavík developed and distributed a fact sheet on both giant hogweed (Figure 2.1) and common hogweed during the summer of 2017. The fact sheet was placed in the mailbox of every home that had hogweed present on the private

property. The purpose of the fact sheet was to educate and make the homeowner or tenant aware of the potential health risks of coming into contact with the phototoxic sap; and recommend methods on how to control the spread of the plant and/or eradicate it completely. In addition to the fact sheet, the City of Reykjavík also posted warning signs in the eradication areas where chemicals were sprayed (Figure 2.2). The outreach information should be available in Icelandic and English, and be distributed throughout the neighborhoods and schools - especially those in a high priority areas – as well as beyond the city boundaries to foster national awareness.

Figure 2.1: Giant Hogweed fact sheet distributed throughout Reykjavík, Iceland.

Giant Hogweed

(*Heracleum mantegazzianum*)

HEALTH WARNING AND SAFETY INSTRUCTIONS

Control and Prevention:

The City of Reykjavik wants to prevent further spread of Giant Hogweed. The distribution is being mapped and all indications of plants, whether in a citizen country or on private grounds, are well received.

Reykjavíkurborg intends to remove plants from the city and in priority sites near schools, playgrounds, and popular outdoor recreation areas. Residents who have Giant Hogweed in their yard are asked to monitor whether they are in close proximity to gardens, and it is recommended to cut flower shoots before they form seeds if the plants are not completely removed.

SAFETY PRECAUTION:

During any attempts at hogweed removal, make sure you have no exposed skin, wear glasses or goggles and conduct the removal on a cloudy day. It is a good idea to clean up thoroughly (shower and wash clothes) immediately following the removal activity.

Figure 2.1 (continued): Giant Hogweed fact sheet distributed throughout Reykjavík, Iceland.

HEALTH AND SAFETY ALERT

- The sap contains toxins that severely damage the skin in the presence of sunlight. Effects include welts, rashes, and blistering, followed by pigmented scarring that may persist for as long as six years. Toxic sap is found in the leaves, stems, flowers, and roots of giant hogweed. Contact with sap can occur by brushing against any broken plant parts, handling plant material, or even by touching tools or mowing equipment that was used for giant hogweed control.
- The area of skin that has been in contact with Hogweed is then photosensitive for up to 6 years after the initial contact event – meaning that exposure to sunlight can re-activate the burn for up to 6 years, so the victim needs to keep the area of skin covered until fully healed.

REMOVAL AND DISPOSAL

- Cut about 15 cm from the ground
- Repeat at least 2 or 3 times over the summer
- Cut the root to a depth of about 20 cm under the soil surface. Use a sharp round shovel
- Work the soil, turning it at a depth of about 24 cm, for example. This will limit regrowth of plants
- Repeat the cutting each year over several years in order to completely get rid of the plant
- If the plants have seeds, avoid spreading them
- Destroy the umbels by placing them in securely closed, sturdy plastic bags. Leave bags in the sun for a least a week
- Do not compost any part of the plant
- To prevent giant hogweed from invading your land again, you can grow new plants in the area cleared. Preferably choose plants that are native to your area
- The use of herbicides or chemical controls can also be applied

Figure 2.2: Chemical warning for Common Hogweed eradication area in Reykjavík, Iceland. (Vesturbærlaug).

2.4 Conclusions

The management of hogweed (*Heracleum* species) in Reykjavík, Iceland, is essential to protect biodiversity, human health, and ecosystem sustainability. It is important to recognize that within all methods of eradication and control of hogweed: various challenges will be presented- such as the increase of Nootka lupin creating more fertile soils, a warming climate, and a decrease in sheep-grazing. This study suggests that the control and eradication of hogweed is very time-sensitive and the ultimate goal is to destroy the plant before it produces seeds. Managing an invasive species in urban areas, in particular Reykjavík, is of great importance in order to maintain biodiversity of native flora, prevent human health hazards, and reduce secondary spread to wilderness and rural areas.

Both local data and information from other countries, in particular the Nordics, can help establish realistic management goals and objectives to address the distribution and potential impacts of hogweed in Reykjavík, Iceland. The city can manage the spread and distribution hogweed through monitoring, public education, and testing various eradication and control methods. A long-term study of at least five years is recommended

to monitor hogweed and their response to management methods, as well as the recovery of managed areas.

Finally, an increase in awareness on the impact of hogweed in Reykjavík is necessary, both in public land sites and private residential areas. By engaging the local community, steps can be taken towards this goal. The current level of education and management of invasive plant species in Iceland is still at a relative new and presents the need for more research and comparison of management methods. Iceland's biodiversity is an increasingly important driver for sustainable management of current and potential invasive species.

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