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Short title: Mapping urban alien plants

Mapping wild chervil (*Anthriscus sylvestris*) and anise (*Myrrhis odorata*) in urban green spaces: a subarctic case study

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Abstract

Urban areas are increasingly recognized as important centers of biodiversity. Nonetheless, invasive species can reduce this biodiversity, and cities can be hubs for alien plant invasions, highlighting the need to monitor urban biodiversity and problematic alien species. The goal of our study was to assess the distribution of wild chervil (*Anthriscus sylvestris* (L.) Hoffm.) and anise (*Myrrhis odorata* (L.) Scop.) in green spaces of Reykjavík, Iceland. This information is necessary to implement the city´s biodiversity strategy regarding invasive species. Both of these alien plants are spreading throughout Iceland, and Reykjavík´s high latitude (≥63° N) location and remoteness makes it an ideal case study to assess alien plant introductions and invasions in subarctic urban areas. We surveyed from May to October 2017 four green spaces (Laugarnes, Vatnsmýri, Elliðaárdalur, and Ægisiða), using AllTrailsPro and ArcGIS mobile applications. ANOVA and Bonferroni correction (post-hoc test) were used to compare the distribution and patch sizes of *A. sylvestris* and *M. odorata* among the study sites. We found that *A. sylvestris* covered at least 10% (15.5 ha) of the total area surveyed (158 ha), while *M. odorata* only covered ≤1 ha. Both plants were abundant near buildings, pathways, riversides, and streams, and they are expanding their distribution in Reykjavík´s green spaces. While *A. sylvestris* is clearly more established and widespread with larger patches (>100 m^2), the distribution of *M. odorata* is more localized, occurring mainly in smaller patches (<100 m^2). We recommend long-term monitoring to further assess *M. odorata*´s invasive potential, as well as testing and adopting integrated weed management strategies via adaptive management to control the distribution of *A. sylvestris* and that of other problematic alien plants. These actions, which are applicable to other subarctic cities, will help foster more proactive management encouraging urban biodiversity.

Keywords: alien plants, distribution, high latitude, invasive species, urban biodiversity

Management Implications

Managing *Anthriscus sylvestris* (wild chervil) and *Myrrhis odorata* (anise) in subarctic urban areas will depend on their distribution pattern and preferred habitat type. It is important to first map their distribution, identify hot spots, and prioritize management areas. Adopting a long-term adaptive management approach will help test and determine the best localized actions ranging from eradication to control of further range expansion. Because *M. odorata* is not as widespread in Reykjavík, monitoring and assessing potential negative impacts is recommended. In addition, proactively testing eradication and control methods locally increases the success of managing *M. odorata* if it becomes invasive in the future. In green spaces that are managed by the city with individual *M. odorata* and *A. sylvestris* seedlings, digging them out with their tap roots before they bloom is a feasible approach to control their spread. Given that *A. sylvestris* thrives well in nutrient rich soil, we also recommend monitoring soil nitrogen levels and monoculture stands of *Lupinus nootkatensis* (Nootka lupine). *L. nootkatensis* is a widespread alien invasive plant in Iceland that fixes nitrogen and facilities the invasion of *A. sylvestris.* In places with long summer daylight hours, such as Iceland, effective mowing frequency needs to be tested locally. When large monocultures of *A. sylvestris* are present, integrated control strategies are likely needed. For example, mowing frequently (≥4 times) in two-week intervals, starting prior to or at peak flowering and continuing throughout the growing season; applying herbicides (e.g. glyphosate) 3-4 times at least for two consecutive years when feasible; tillage and native grass seeding; and/or controlled grazing (Luoma 2019). Finally, public outreach through social media and harvesting events focusing on the edible uses of *M. odorata*, *A. sylvestris*, and other edible problematic alien plants, will increase public participation in management efforts.

Introduction

Urban biodiversity conservation is high on the agenda for cities around the globe as alien plant invasions are diminishing local plant diversity (Keller et al. 2011; Nilon et al. 2017; Pimentel et al. 2005). Urban areas tend to be hotspots for introductions and invasions of alien plants, while hosting high plant richness (Gaertner et al. 2017; Shochat et al. 2010). Alien plants are becoming an increasing problem due to global economies, tourism and trade, and the risk of invasions to disturbed ecosystems (Chytrý et al. 2008; Clark and Johnston 2011; EEA 2016; Walker and Steffen 1997). In fact, Target 6 of the Kunming-Montreal Global Biodiversity Framework aims to reduce and manage the spread and impacts of invasive alien species on biodiversity (CBD 2023). Moreover, addressing invasive alien plants is necessary to meet the UN Sustainable Development Goal 15 (Life on land) (SDGS 2015).

The introduction of alien plants poses multiple threats to ecosystem functions and services, native biodiversity, landscape aesthetics, and agriculture (Pejchar and Mooney 2009; Pimentel et al. 2005; Simberloff et al. 2013). This is worrisome, as the negative effects of invasive alien plants can be gradual but end up having large-scale, long-lasting, and often irreversible consequences (EEA 2016; Luoma 2019; Simberloff et al. 2013). Urban areas can be larger in size and have high habitat heterogeneity, leading to greater plant richness (native and alien), than the neighboring countryside (Kühn et al. 2004; Lososová et al. 2012a; Pyšek, 1998; Wania et al. 2006). The invasibility of habitats varies depending on the fluctuation of available resources, especially nutrients, and the frequency and level of habitat disturbance (Pyšek et al. 2009). Cadotte et al. (2017) generated categories that make alien species thrive in urban areas such as propagule pressure, reduced negative interactions, resource supply, and the combination of altered and unique environmental conditions (Luoma 2019). For example, plant invasions in urban areas can start from the spread of ornamental plantings (propagule pressure) or where suitable habitat conditions exist (resource supply) (Cadotte et al. 2017; Lee et al. 2015; Mayer et al. 2017).

The Arctic provides an interesting area to explore problematic alien plants because until recently it has experienced relatively limited plant introductions (Lassuy and Lewis 2013). This is due to the remoteness of the region, challenging climatic and growing conditions, low number of inhabitants, and limited trade (Alsos et al. 2007). Researchers have found that alien plant invasions in the Arctic are mostly local, with no invasive plants occurring in multiple Arctic regions (Wasowicz et al. 2019). Furthermore, it seems that Arctic areas with larger human populations and older settlements are impacted more by alien plants. The Arctic is warming three times faster than other areas and with commerce increasing in the area, it is likely that alien plant distribution and invasions will expand (Rantanen et al. 2022; Rantanen 2024; Wasowicz et al. 2019; Zhou et al. 2024). Warming is also apparent in subarctic areas; for example, in northwestern Iceland, between 1981-2020, mean temperatures rose 2.6 times more per decade than the global average (Bannan et al. 2022). Currently, 341 alien vascular plant taxa have been reported in the Arctic (including Iceland), of which 11 are classified as invasive (Wasowicz et al. 2019). Although most alien plants in the Arctic are found in urban areas, there is limited knowledge about their distribution and impact on native plants.

The city of Reykjavík is an ideal location for a case study to research the invasion process of alien plants in cities that are remote, high latitude (≥63° N), and where biodiversity and growing season are limited by challenging weather conditions (Gretarsdottir et al. 2004; Luoma 2019). Iceland has only 45% vegetation cover, the lowest in Europe, and >40% of the land is

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deserts, making it a priority to conserve native plant communities (Arnalds, 2015). Currently, there are 282 casual alien vascular plants (no self-sustaining populations) and 65 naturalized plants, including two which are classified as invasive in Iceland (Wasowicz 2020). Most of these naturalized plants are present in urban areas like Reykjavík. Recently, the total cost of invasive alien species (plants and animals) in Iceland was reported as 25.45 million USD; however, this is likely underestimated (Kourantidou et al. 2022).

Invasive species are recognized as an area of focus in Reykjavík´s biodiversity policy (Garðarsson et al. 2016). Their biodiversity strategy includes actions such as mapping and identifying invasive plants, public engagement, and implementing management actions (Garðarsson et al. 2016; Luoma 2019). Moreover, the city has published a strategic plan, the Green Deal, which mentions their vision of maintaining and managing biodiversity and addressing the costs of invasive species (Anonymous 2022). Alien plants, like giant hogweed (*Heracleum mantegazzianum* Sommier and Levier) already threaten public health locally (Anonymous 2016b; Sigurgeirsdóttir and Hilmarsdóttir 2017), and Nootka lupine (*Lupinus nootkatensis* Donn ex Sims) may impact insect pollinators in urban areas (Willow et al. 2017). Other plants of concern are wild chervil (*Anthriscus sylvestris* (L.) Hoffm.) and anise (*Myrrhis odorata* (L.) Scop.), which have been spreading throughout Iceland, but their distribution in Reykjavík´s green spaces is not well understood (IINH 2024; Luoma 2019; Magnússon 2011; Wasowicz et al. 2013).

Green spaces can vary in size and shape, ranging from wetlands and narrow coastal grassy pathways to large forested outdoor areas, creating an urban matrix with various green segments (Lepczyk et al. 2017). Data on the distribution patterns of alien plants in Reykjavík´s green areas is limited, making it difficult to determine potential impacts, develop management strategies, and meet biodiversity goals. Given these issues, the goal of our study was to assess the distribution of *A. sylvestris* and *M. odorata* in four popular and diverse green spaces in Reykjavík. We focused on characterizing the growth patterns (scattered plants versus dense stands), distribution, and habitats (e.g., wetland, riversides, and grasslands) of these two plants. Another goal was to create a baseline for tracking *A. sylvestris* and *M. odorata* within the city. This baseline helps to generate management recommendations for land planning actions, fostering urban biodiversity, and tracking other emerging problematic plants. Although we focus on Reykjavík, our study provides insight into potential impacts and risks of emerging alien plant invasions to urban green spaces that are applicable to other subarctic and Arctic cities.

Materials and Methods

Target Species

Wild Chervil (A. sylvestris)

This vascular plant normally grows 0.3–1.5 m tall and is either a short-lived perennial or herbaceous biennial plant (Darbyshire et al. 1999; Magnússon 2011); but in Iceland it can reach 2 meters in height (M Luoma, unpublished data). *A. sylvestris* blooming peaks by mid-June in Iceland, with most seeds produced in early August (Figure 1) (Magnússon 2011; Luoma 2019). This plant can reproduce asexually from the root buds, but also sexually by producing ≤ 10,000 seeds (Darbyshire et al. 1999). Seed dispersal is via human activities (e.g., agriculture), water, and wind (Hansson and Persson 1994; Magnússon 2011). *A. sylvestris* is native to Eurasia (Magnússon 2011; Wasowicz et al. 2013) but alien to Iceland, Svalbard (Alsos et al. 2015; Gederaas et al 2012), Greenland, Faroe Islands, the United States (USDA 2024a), Canada (Darbyshire et al. 1999), central and southern Africa, New Zealand, and South Georgia (Magnússon 2011). The first records of *A. sylvestris* in Iceland are from the city of Akureyri in 1927 (Óskarsson 1932), and the plant was not considered invasive in Iceland until the last two decades when it became evident that its distribution and abundance had increased across the country (Magnússon 2011). Researchers suspect that *A. sylvestris* began spreading in urban areas in Iceland as a garden escape (Magnússon 2011; von Schmalensee and Stefánsson 2009).

A. sylvestris is forming dense monoculture stands along waterways and roads (Luoma 2019; Magnússon 2011; von Schmalensee and Stefánsson 2009). It spreads rapidly, replaces other plant species, facilitates alien plant invasions, increases soil erosion, degrades cultural landscapes, and is difficult to eradicate once it becomes established (Darbyshire et al. 1999; Førde and Magnussen 2015; Hansson and Persson 1994; Jørgensen et.al. 2013; Magnússon 2011). *A. sylvestris* often spreads in former pasturelands, but urban areas are also vulnerable to the negative impacts of this plant (Luoma 2019; Magnússon 2011; Pilto 2012).

Anise (M. Odorata)

M. odorata is a perennial plant that looks very similar to *A. sylvestris* but has several features that differ from *A. sylvestris* such as strong anise-like odor, larger seeds, and lighter green leaves

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(Figure 2) (Kristinsson 2013; Luoma 2019). *M. odorata*´s native range covers central and southern Europe (Kew Science 2024). The alien distribution of *M. odorata* includes the Nordic countries, Baltic States, northern Russia, United Kingdom, Belgium, Netherlands, Poland, Czech Republic, Ukraine, North America, and New Zealand (iNaturalist-NZ 2024; Kew Science 2024; Native Plant Trust 2024). *M. odorata* is an ornamental plant used for medicinal purposes and food consumption (Penny 2024; Petřík et al. 2019; Rančić et al. 2005), making garden escape a likely dispersal pathway. In Iceland, *M. odorata* is classified as an alien plant and is yet to be evaluated for invasiveness (von Schmalensee 2010). The first known record is from 1936, and this plant has been expanding its distribution in Iceland, especially in urban areas (IINH 2024; Seebens et al. 2017). Reproduction of *M. odorata* is by taproot and seeds, similar to *A. sylvestris* (Penny 2024). *M. odorata* is present in farms, woodlands, and along streams, as well as urban gardens throughout Iceland (IINH 2024).

Study Areas

We assessed the distribution of *A. sylvestris* and *M. odorata* in four green spaces in Reykjavík, located in Laugarnes (64.15°N, 21.88°W), Vatnsmýri (64.14°N, 21.94°W), Elliðaárdalur (64.12°N, 21.85°W), and Ægisíða (64.14°N, 21.96°W) (Figure 3). These areas represent a heterogeneity of green spaces in the city providing a gradient of urban habitats. Together these four areas include five of the seven urban habitat types described by Lososová et al. (2012a) for central European cities, ranging from densely built residential areas to recently disturbed sites. These sites will also act as a foundation to build a database for local green spaces and their biodiversity.

Laugarnes is a popular outdoor coastal area with a museum and some residential buildings, located in north-central Reykjavík (Figure 3). Many archaeological sites are found in this area, some dating back to the settlement period (c. 870-930), and during World War II hosted a military community, and was also used for pastureland (Guðmundsdóttir 2003; Hallgrímsdóttir 1996). Our study area in Laugarnes is grassland habitat, where invasive and other alien plants of concern such as *H. mantegazzianum* and *L. nootkatensis* are also present. Laugarnes fits the urban habitat type 7, a mid-successional site, from Lososová et al. (2012a) with the exception that our study site has been abandoned for more than 15 years and some sections are mowed by the city.

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Vatnsmýri is located next to the University of Iceland and the Reykjavík Airport in the western part of Reykjavík (Figure 3). This wildlife nature reserve is large, approximately 3.7 ha in size, and is mostly wetland habitat. We only surveyed the outer grassland area by the wetland, because the inner part of the nature reserve is closed in the summer during the nesting bird season (Luoma 2019; Pálsson 2003; Sigurðsson 2015). Vatnsmýri hosts 83 vascular plants and 65 of them are native to Iceland (Pálsson 2003). This area has been experiencing major urban development, impacting the reserve (Garðarsson et al. 2016). In 2013 and 2014, improvements to the bird nesting habitat were implemented, which included increasing the water level and decreasing the elevation of wetland islands via soil and plant removal to manage alien plants, such as *A. sylvestris* (Luoma 2019). Vatnsmýri is an example of an urban habitat type 6, an early successional and recently disturbed site, as described by Lososová et al. (2012a).

Elliðaádalur, a large green space, is a popular biking, hiking, and fishing area. This area in the eastern part of Reykjavík (Figure 3) was important for forestry and had summer homes and sheep farms (Anonymous 2016a; Luoma 2019). Today, Elliðaárdalur has various landscapes, with a mixture of forest and grasslands habitats, and where the Elliðaár River flows in the middle of the area. Elliðaárdalur is home to 25 bird species, and at least 315 vascular plant species, of which 179 (57%) are native plants (Anonymous 2016a; Pálsson 2004). Our study area in Elliðaárdalur included Geirsnef (a popular dog park) and its surroundings, as well as Háubakkar (a protected area) (Anonymous 2018). Elliðaárdalur is a very large and heterogenous area, and therefore only Geirsnef can be described as habitat type 5, an urban park that is mowed frequently and has 10-20% tree cover of downy birch (*Betula pubescens* Ehrh.) and willow (*Salix* spp) (Lososová et al. 2012a). In addition, Elliðaárdalur is surrounded by both habitat type 4, a residential area built after the 1960s, with shrubs and trees, scattered lawns, and habitat type 3, consisting of older family houses with gardens (Lososová et al. 2012a.).

The Ægisíða study site is a flat area between a protected shoreline and a residential street in the northwest of Reykjavík (Figure 3). Ægisíða is a grassland habitat with some large monocultures of Norwegian angelica (*Angelica archangelica* L.) and *A. sylvestris* near a residential house. Previously, this area was farmland that became urbanized, and a 1954 aerial photo shows more houses and industrial buildings than are currently present (Borgarvefsjá 1954). Ægisíða is near to the Reykjavík airport and is popular for cycling, dog walking, and jogging. Overall, this area represents habitat type 3, with a series of older family houses with gardens lining the street across from the shoreline (Lososová et al. 2012a).

Data Collection and Statistical Analyses

AllTrailsPro (2017) and ArcGIS mobile applications were used to survey the study areas between May 31 and October 25, 2017 (Luoma 2019). GPS locations of *A. sylvestris* and *M. odorata* were recorded in the four study sites (Luoma 2019). ArcGIS was used to draw polygon shapes of the distribution of *A. sylvestris* and *M. odorata* and their potential overlap. The SHAPE_Area polygon feature was used to calculate the distribution area of both plants. Plant distribution was classified as either scattered plants or dense plant stands/patches of *A. sylvestris* and *M. odorata* (Luoma 2019). The classification was either a) ≥3 plants per m^2 for dense plant stand/patch or b) a plant patch >0.5 m^2 but with ≤2 for scattered plants. Typically, a scattered distribution for *M. odorata* was an individual plant in ≤1 m^2. ArcMap 10.4.1. was used to create the distribution maps of *A. sylvestris* and *M. odorata*. We used WGS 1984 with a Prime Meridian set for Greenwich geographic coordinate system to gather the data, which was projected as WGS 1984 with metric linear unit. Given that *A. sylvestris* and *M. odorata* look similar to each other (Figure 1 and Figure 2) and other plants such as bishop´s goatweed (*Aegopodium podagraria L.*), the surveys were conducted on foot rather than using a drone. Guides by Kristinsson (2013), Kristinsson et al (2018), and Flora of Iceland (2024) were used for plant identification. The data were normally distributed and there was homogeneity of variance, so we used ANOVA and a Bonferroni correction for the post-hoc test ($\alpha = 0.05$) to compare the distribution and patch size of both plants among the four study sites, running the analyses on SPSS® 24 software (Luoma 2019).

Results and Discussion

Wild Chervil (A. sylvestris) and Anise (M. odorata) Distribution Patterns

Overall, 158 ha (all four study areas) were surveyed, of which *A. sylvestris* and *M. odorata* covered 11% (Luoma 2019). *A. sylvestris* was more prevalent, encompassing 10% of the total area surveyed, and having the greatest cover per area surveyed in Vatnsmýri (23%) (Table 1). *M. odorata* coverage was low (≤0.5%) with the exception of Laugarnes (>8%) where it was more common than *A. sylvestris*. We found no significant difference in plant cover among the study

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areas for *A. sylvestris* (F(3, 16) = 0.119, p = 0.947) (Luoma 2019). Elliðaárdalur had the largest total area with *A. sylvestris*, encompassing 13 ha (Table 1).

We found 98 patches of *M. odorata*, ranging from <1 m^2 to a dense stand of 3875 m^2 (Figure 4; Luoma 2019). The mean *M. odorata* patch was 158 m^2 (SE ± 58), but because the number of patches per study site varied from 1 to 83, we were unable to compare their size statically among the study areas. A total of 396 *A. sylvestris* patches (Figure 5) were present in the study sites, including 34 scattered plant patches. *A. sylvestris* patch sizes varied greatly, ranging from <1 m^2 to >1.2 ha, and were on average 392 m^2 (SE ± 55), (Table 2; Luoma 2019). We found significant differences between the sites regarding the mean patch size of *A. sylvestris* (F(3, 392) = 5.584, p = 0.001), with Vatnsmýri (p = 0.041) and Elliðaárdalur (p = 0,001) having significantly bigger patches than Laugarnes (Table 2; Luoma 2019). We also found that patch size varied significantly within Elliðaárdalur (F(5, 239) = 11.948, p = 0.000). For example, the *A. sylvestris* patches in the Háubakkar protected area were significantly smaller (p < 0.001; patch size = 106 m^2 ± 57) than patches to the east of Geirsnef (patch size = 2425 m^2 ± 780) (Luoma 2019). Similarly, below Geirsnef there were significantly smaller *A. sylvestris* patches (241 m^2 ± 44) than those in the east (p < 0.001) and northeast (p = 0.017; patch size = 1428 m^2 ± 644) of Geirsnef (Luoma 2019). Moreover, Geirsnef patches were significantly smaller (p < 0.001; patch size = 574 m^2 ± 168) than patches east of Geirsnef.

Study Site Distribution

In Laugarnes, there was minimal overlap between *A. sylvestris* and *M. odorata*. *A. sylvestris* was a mosaic of monoculture stands, scattered plants and smaller patches around the site (Figure 6) (Luoma 2019). In addition, three very large *M. odorata* stands were present, two of them near a former building site in the western part. A few large *M. odorata* stands were found next to patches of *A. sylvestris* near residential buildings. The majority of the patches (64%) of *A. sylvestris* and *M. odorata* in Laugarnes were <10 m^2 (Figures 6 and 7).

Vatnsmýri had a very large *M. odorata* stand mixed with *A. sylvestris* next to the heavily trafficked Hringbraut Street along the northeast pathway (Figure 7) (Luoma 2019). The majority *A. sylvestris* stands (77%) were large (>100 $m^{2)}$ and dense (Figure 4), scattered along the pathways and water (Figure 7).

In Elliðaárdalur, large, scattered and dense patches of *A. sylvestris* were present in and around Geirsnef by the Elliðaár River (Figure 8). *M. odorata* was absent in Geirsnef (Figure 8),

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but was found by the walking paths in the inner parts of Elliðaárdalur as dense stands (Figure 8), without overlapping with *A. sylvestris* (Luoma 2019). Furthermore, these inner areas in Elliðaárdalur had predominantly dense stands of *A. sylvestris* along the river and pathways. Most stands (75%) of *A. sylvestris* and *M. odorata* in Elliðaárdalur were ≥10 m^2 (Figures 4 and 5).

A. sylvestris and *M. odorata* occurred in scattered and dense stands in the south and northwest areas of Ægisíða (Figure 9), and there was no overlap between the species (Luoma 2019). *A. sylvestris* was more common in Ægisíða than *M. odorata*, and most patches (71%) of both plants were >10 m^2 (Figures 4 and 5).

Current Status and Recommended Management Actions

The distribution of *A. sylvestris* was more widespread than expected, totaling 10% of the area surveyed in Reykjavík (Luoma 2019). In contrast, *M. odorata* distribution is more localized, found in fewer areas as remnants of abandoned gardens or farmlands. Although there is very little overlap between the two species, they both thrive in urban settings, particularly near waterways, buildings, pathways and roads. Similar distribution patterns have also been recorded in northern and northwestern Iceland, United Kingdom, the Netherlands, and North America (Bjarnadóttir 2014; Darbyshire et al. 1999; GBIF Secretariat 2023; Jónsson and Þórðarson 2018; National Museums NI 2023; TNC 2010; van Mierlo and van Groenendael 1991).

Overall, large monoculture stands of *A. sylvestris* are enabling the spread of the species in Reykjavík. However, Æegisíða is an exception where *A. sylvestris* does not seem to be expanding in large, scattered stands, but rather smaller patches of 1-3 plants. Frequent mowing in Ægisíða (4 times/summer) may be preventing seed dispersal and the formation of larger stands from individual plants as the larger stands of *A. sylvestris* and *M. odorata* are beyond the grass cutting range (Luoma 2019). A combination of control actions is needed to manage *A. sylvestris* (ISC, 2019). We advise digging out individual seedlings and their tap roots before blooming in areas where the grass is mowed or where small patches of *A. sylvestris* are present (Nova Scotia Department of Agriculture 2003). If feasible, Canadian resource managers recommend herbicide use (e.g. glyphosate) to prevent seeding in large stands of *A. sylvestris.* If herbicides are not an option, then mowing frequently every two weeks prior to blooming or at peak flowering and thereafter is recommended (ISC 2019; Nova Scotia Department of Agriculture 2003). Moreover, the most effective control strategy of *A. sylvestris* is a combination of mowing before flowering,

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application of herbicides, tillage and native grass seeding (Luoma 2019; Miller and D'Auria 2011). Based on management experiments in north and northwest Iceland, researchers suggest applying herbicide treatments with glyphosate (e.g., Clinic, at a 1:120 concentration) at least 3-4 times for two consecutive years to eradicate *A. sylvestris* (Bjarnadóttir 2014; Jónsson and Þórðarson 2018). This treatment seems best for eradicating smaller, isolated stands of *A. sylvestris* but not large, well-established communities (Bjarnadóttir 2014). They also mention grazing (e.g., sheep) as another potential tool warranting research (Bjarnadóttir 2014; Jónsson and Þórðarson, 2018). In urban nature reserves such as Vatnsmýri, where access is partly restricted during the summer, a strategy that combines hand pulling seedlings and controlled grazing (e.g. sheep, goats, or pigs) can be tested for *A. sylvestris.* In addition, for open access areas, frequent mowing ≥4 times before blooming and pulling out individual plants with roots seems to be effective to control the spread of both *A. sylvestris* and *M. odorata* (ISC, 2019). Furthermore, monitoring the plant community in urban nature reserves would help detect changes in species composition and the effects on biodiversity. Urban nature reserves, such as Vatnsmýri, have high conservation value (Garðarsson et al. 2016), making them a priority to manage invasive and problematic alien plants to prevent the loss of biodiversity (Darbyshire et al. 1999; Hansson and Persson 1994).

Another important management strategy is to identify urban hotspots of invasive and problematic alien plants. In Reykjavík, Laugarnes seems to be a hub for invasive or problematic alien plants, where *A. sylvestris* and *M. odorata* grow together with *L. nootkatensis* and *H. mantegazzianum*. The presence of *H. mantegazzianum* is a great concern because it is a serious health hazard, and it shades native plants with its tall stems (≥ 2 m) and large leaves. In sunny weather, when *H. mantegazzianum* sap is exposed to ultraviolet radiation, it can cause serious skin burns (Nielsen et al. 2005). The lowest native plant cover of all the study sites was in Laugarnes, making the presence of *A. sylvestris* worrisome. Several studies in central Europe have shown that areas with *A. sylvestris* are vulnerable to further alien plant invasions, particularly plants that thrive in nutrient rich soils (Godefroid and Koedam 2003; Hansson and Persson 1994; Pyšek et al. 2009). Areas like Laugarnes require a management strategy that targets multiple invasive plants. In the past, Reykjavík has implemented eradication efforts for *H. mantegazzianum* in parts of Laugarnes that included mowing, manual cutting and herbicide treatment. However, an assessment of the effectiveness of these efforts is needed, as well as

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testing additional control actions to manage other problematic alien plants. Furthermore, we recommend monitoring the distribution and soil nitrogen levels of green spaces with *L. nootkatensis* such as Elliðaárdalur, as they may be invaded by *A. sylvestris* (Magnússon 2011).

In the future, the abundance and distribution of *A. sylvestris* is likely to increase with climate change, emphasizing the need to manage this plant now. Wasowicz et al. (2013) predicted that for *A. sylvestris,* its climatic niche in Iceland will increase greatly, enabling it and other alien plants like *M. odorata* to colonize new habitats. Our study shows that foot surveys using AllTrails and ArcGIS Collector applications to record the distribution of alien plants is effective. These mapping actions may potentially be complimented by remote sensing, a method which also requires ground truthing to train and validate the data collection. Currently, researchers at the University of Iceland are exploring drones and satellite imaging as additional tools to distinguish and map *A. sylvestris* and *M. odorata* in Reykjavík.

Future Research Priorities

Currently, *M. odorata* is less prevalent in green spaces of Reykjavík compared to *A. sylvestris*. The largest total area with *M. odorata* is 1 ha (Laugarnes), likely planted several decades ago. Most of the *M. odorata*´s distribution in Reykjavík is scattered plants and smaller patches (<100 m^2). This distribution may be due to *M. odorata* not having spread to all available habitat, or to differences in habitat suitability; however further research is needed to test these hypotheses. For example, studies looking at differences in soil moisture and nutrients, as well as levels of disturbance, among others, will help assess the influence of environmental and anthropogenic factors in alien plant distribution. Although *M. odorata* is not as common as *A. sylvestris*, testing local eradication and control actions should be implemented to prevent it from spreading further and potentially causing negative impacts. The ongoing and increasing alien distribution of *M. odorata* is not limited to Iceland, as it has also been spreading in the United Kingdom and more recently in New Zealand (Braithwaite 2020; GBIF Secretariat 2023; iNaturalist-NZ 2024; Seebens et al. 2017). Like *A. sylvestris, M. odorata* is abundant in roadsides close to residential buildings and is suspected to have escaped from gardens (Gederaas et al 2012; Luoma 2019; National Museums NI 2023; Stroh et al 2020; USDA 2024b). Pyšek et al. (2012) classify *M. odorata* as a plant escaping cultivation and forming stable populations in the wild. Nonetheless, *M. odorata* is not categorized as an invasive plant in Iceland or Europe; however, in Norway it is classified as having a very high invasion potential (Gederaas et al 2012; Solstad et al. 2023). We

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recommend long-term monitoring and plant community surveys to assess if *M. odorata* is becoming an invasive plant in Iceland. Regarding proactive management to test and track, areas with single plants and small patches of *M. odorata* can be dug out with relatively low effort in early summer. In contrast, large stands may require multiple mowing treatments before blooming, but the frequency of mowing needs to be evaluated locally. In addition, public campaigns focusing on the culinary uses of *M. odorata* would help increase awareness about the plant and foster control efforts in private gardens and green spaces in the future (Hussain et al. 1990; Lim 2015). We have, for example, organized *M. odorata* and *A. sylvestris* harvesting events in various green spaces in Reykjavík and neighboring towns since 2021, which have become popular with the public. Moreover, we have created a social media platform, "Borgarnáttúra - Urban Biodiversity Iceland", to further promote awareness and collaboration with multiple stakeholders.

Monitoring both invasion pathways and alien plant distributions, which are expected to accelerate with climate change in the Arctic, will facilitate effective strategies that promote urban biodiversity (Wasowicz et al. 2013, 2019). A single alien plant can have detrimental effects when it increases its distribution and becomes problematic by outcompeting native plants (Vilà et al. 2011). Several Central European cities have seen such pattern, showing that some alien plants promote biotic homogenization, thus causing major problems in highly urbanized areas (Lososová et al. 2012b). This is a concern for Reykjavík and other subarctic cities even though this process can take time. Urban areas can provide suitable habitats for alien plants, as disturbed urban habitats often enable these plants to form large populations (Cadotte et al. 2017). Cadotte et al. (2017) also emphasize that to prevent invasive plants from spreading beyond city limits, it is important to monitor and control them in urban areas.

As a case study, our research establishes a baseline for problematic alien plants in heterogenous green spaces of a relatively young and remote subarctic city. *A. sylvestris* and *M. odorata* are spreading in Reykjavík´s green spaces, but with different distribution patterns. These species show minimal overlap in distribution; *A. sylvestris* is more widespread, and *M. odorata*´s invasive potential still needs to be assessed. It is crucial to understand the ecology and abundance of alien plants in a city to achieve sustainable urban management and planning of green spaces. For example, large and dense patches of *A. sylvestris* alter landscape aesthetics and may negatively impact native plant habitats for birds, insects, and invertebrates, possibly changing ecosystem functions (Førde and Magnussen 2015; Willow 2017). Our study suggests that various management strategies will be needed given the different patterns of distribution of *A. sylvestris* and *M. odorata* in Reykjavík. Ultimately, an adaptive management strategy that is proactive and long-term, involving monitoring, public participation, and various management actions, will increase the success in managing problematic alien plants and fostering biodiversity in subarctic cities like Reykjavík (Zalba and Ziller 2007).

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Competing Interests

Competing interests: The authors declare none

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Table 1. Distribution of *Anthriscus sylvestris* and *Myrrhis odorata* in open areas of Reykjavík in 2017. The total area (ha = hectares) where *Anthriscus sylvestris* and *Myrrhis odorata* were present is shown, as well as the total area surveyed for each site. In addition, the cover (%) of *Anthriscus sylvestris* and *Myrrhis odorata* for each area is presented.

Study site	**Total area surveyed (ha)**	**Total area with As (ha)**	**Total areas with Mo (ha)**	**Mo %**	**As %**
Ægisíða	20,72	0,24	0,03	0,1	1,2
Elliðaárdalur	116,19	12,77	0,46	0,4	11
Laugarnes	12,31	0,51	1,01	8,3	4,1
Vatnsmýri	8,73	1,99	0,04	0,5	22,8

As = *Anthriscus sylvestris*, Mo = *Myrrhis odorata*

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Table 2. Average patch size (m^2) of *Anthriscus sylvestris* among open areas of Reykjavík in 2017. Number of patches includes both dense plant stands (≥3 plants per m^2) and scattered plant patches (>0.5 m^2 but with ≤2 plants).

Study site	**Number of patches**	**Mean patch size (m^2 ± SE)**	**Smallest patch (m^2)**	**Largest patch (m^2)**
Ægisíða	11	221,8 ± 117,8	0,57	1254,4
Elliðaárdalur	245	521,1 ± 85,0	0,001	12251,5
Laugarnes	109	46,7 ± 10,1	0,02	520,5
Vatnsmýri	31	641,9 ± 136,3	0,88	3312,2

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Figure 1. *Anthriscus sylvestris* blooming in Iceland. Photo by Mariana Tamayo.

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Figure 2. *Myrrhis odorata* blooming in Iceland. Photo by Mervi Luoma.

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Figure 3. Study areas in Reykjavík are highlighted in red. 1. Laugarnes, 2. Vatnsmýri, 3. Elliðaárdalur, 4. Ægisíða. Scale 1:24.000

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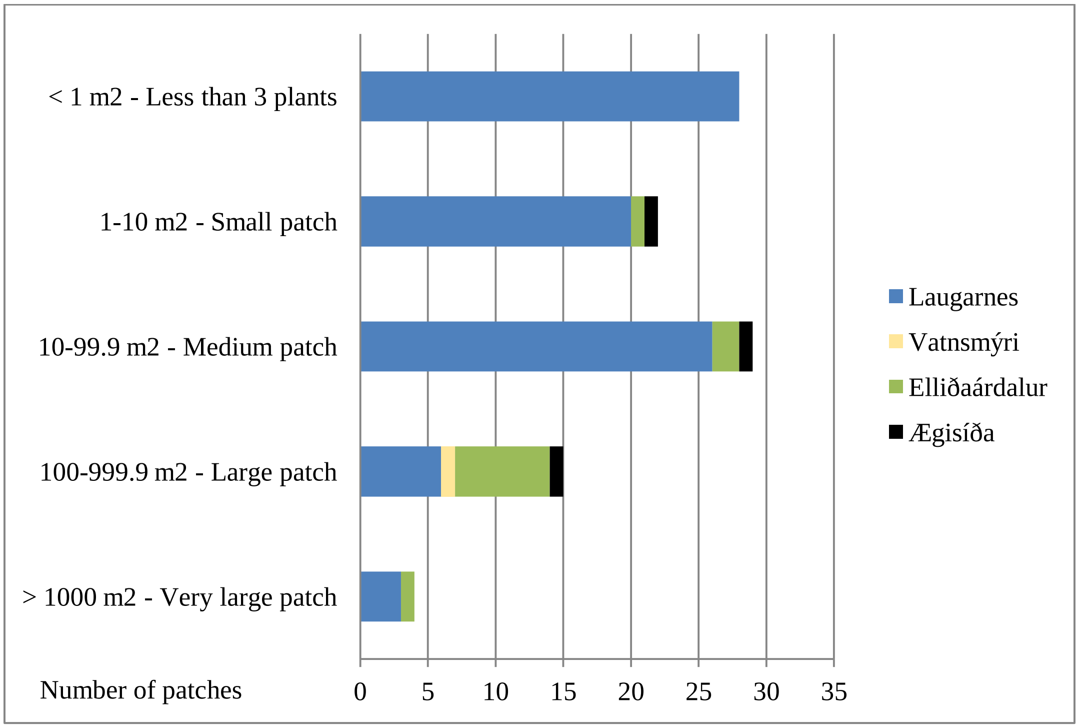

Figure 4. Size and frequency of *Myrrhis odorata* patches in open areas of Reykjavík in 2017.

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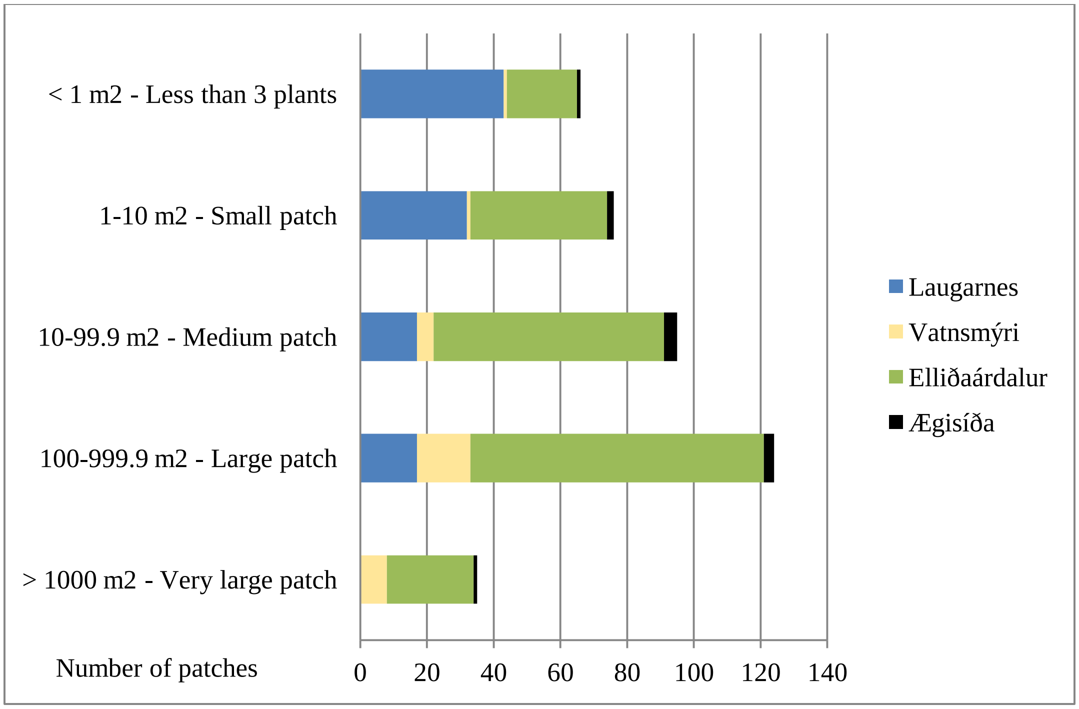

Figure 5. Size and frequency of *Anthriscus sylvestris* patches in open areas of Reykjavík in 2017.

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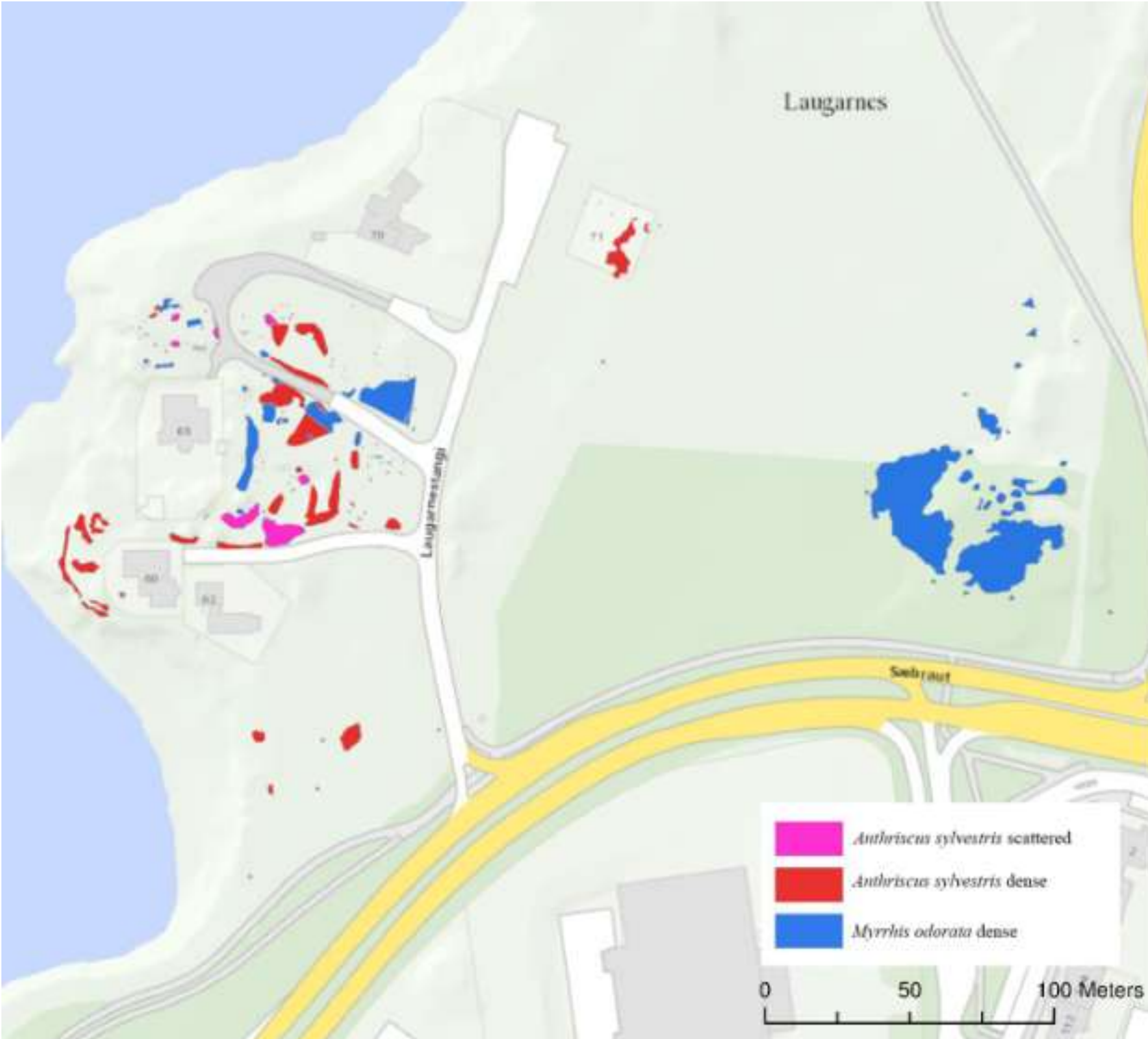

Figure 6. Distribution of *Anthriscus sylvestris* and *Myrrhis odorata* in Laugarnes, summer 2017. The distribution of *Myrrhis odorata* in Laugarnes includes both individual plants and dense patches.

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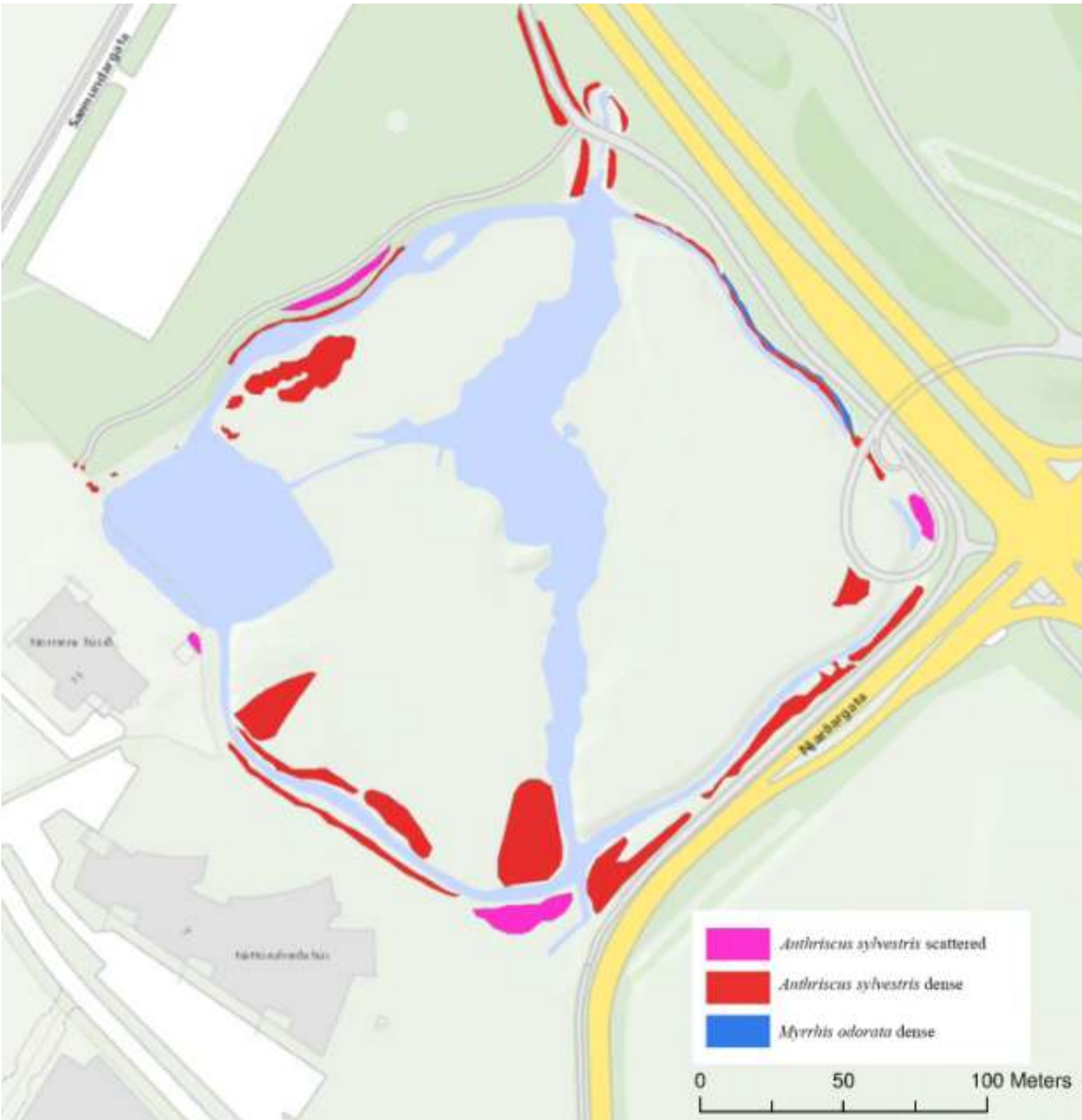

Figure 7. Distribution of *Anthriscus sylvestris* and *Myrrhis odorata* in Vatnsmýri, summer 2017.

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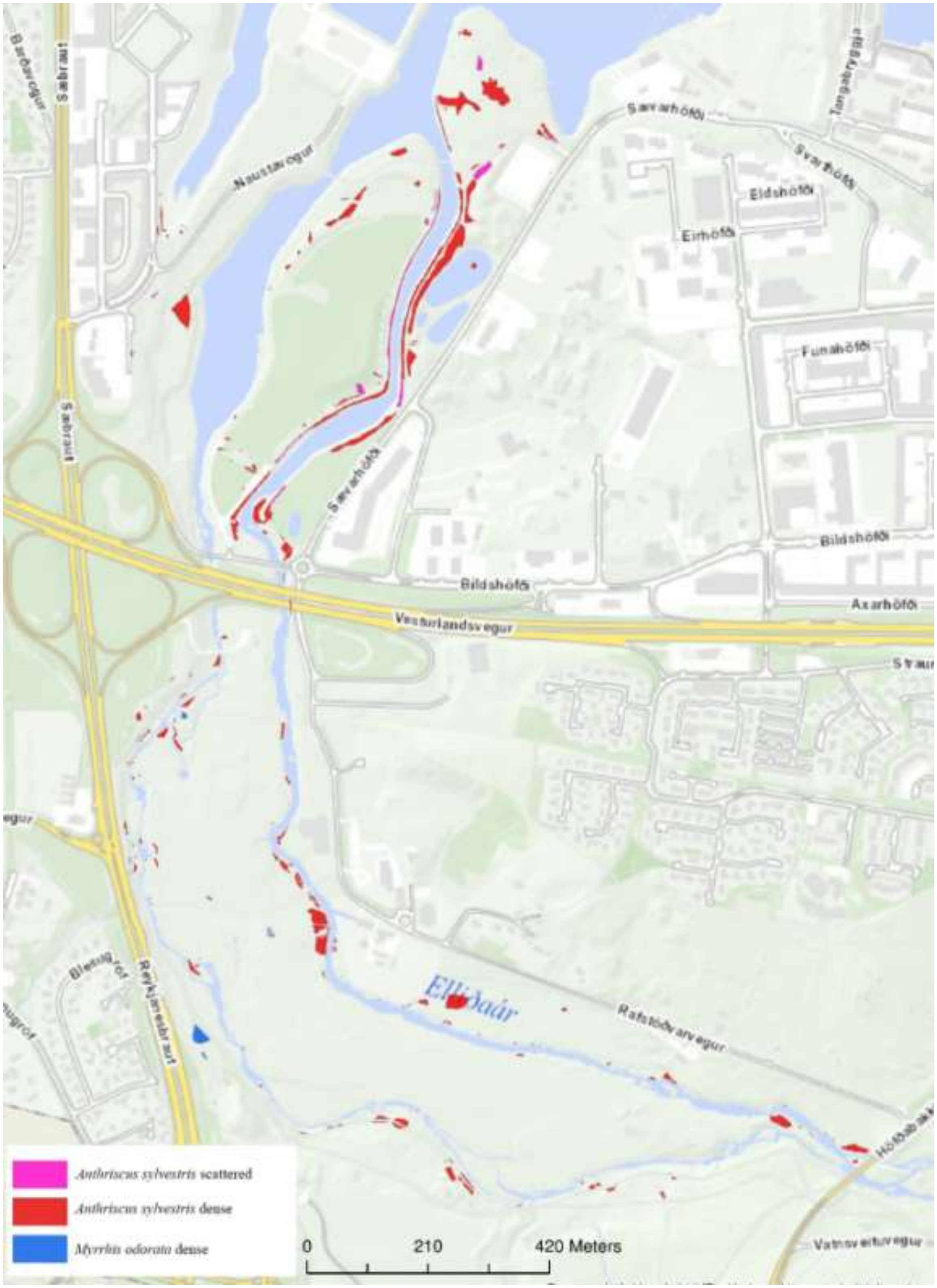

Figure 8. Distribution of *Anthriscus sylvestris* and *Myrrhis odorata* in Elliðaárdalur, summer 2017.

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Figure 9. Distribution of *Anthriscus sylvestris* and *Myrrhis odorata* in Ægisiða, summer 2017.

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