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Invasive plant species in Swedish domestic gardens

Developing evidence-based guidelines for communication with garden owners

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Abstract

Invasive species pose a significant threat to biodiversity, with domestic gardens being one of the primary introduction pathways for invasive terrestrial plants. Climate change is predicted to exacerbate biological invasions in the northern regions of the globe. Despite their ecological importance, private domestic gardens remain understudied in invasion biology research. This thesis examines invasive plant species in Swedish domestic gardens, combining ecological inventories with investigations of garden owners' knowledge, values, and management practices, with the aim of developing evidence-based guidelines for communicating with domestic garden owners about invasive species. Methods vary from field inventories, expert workshops, semi-structured interviews and a postal survey disseminated to garden owners in three diverse bioclimatic areas of Sweden. The results from a garden case study revealed that domestic gardens can contain a great diversity of species. They showed high compositional uniqueness and no correlation between the number of invasive species and garden size. A postal survey, directed at garden owners in the biosphere reserves Voxnadalen, Lake Vänern Archipelago and Mount Kinnekulle, and Blekinge Archipelago, revealed several knowledge gaps. Many of the respondents were unable to identify common invasive plant species, and most were uncertain of how climate change can be expected to impact invasive species. Garden owners prioritise aesthetics, hardiness, habitat suitability and biodiversity support over the species' geographical origin when selecting plants for their gardens. Personal experience of biodiversity loss in their surroundings, which respondents attributed to invasive species, was associated with a significantly higher likelihood of having undertaken management actions. Traditional management methods like hand weeding and digging were most commonly used and were perceived as effective. In addition, regional differences in responses highlighted the need for locally adapted communication. The results enabled the identification of evidence-based communication needs to guide communicators at national, regional, and local levels regarding what information to include in their messaging.

Keywords: invasive alien species, domestic gardens, risk communication, climate change, horticulture

Invasiva växter i svenska privata trädgårdar. Utveckling av evidensbaserade riktlinjer för kommunikation med trädgårdsägare

Abstract

Invasiva arter utgör ett betydande hot mot biologisk mångfald, och privata trädgårdar är en av de främsta introduktionsvägarna för invasiva terrestra växter. Klimatförändringar förväntas förvärra biologiska invasioner i de norra delarna av världen. Trots deras ekologiska betydelse i urbana miljöer är privata trädgårdar fortfarande otillräckligt studerade inom invasionsbiologin. Denna avhandling undersöker invasiva växtarter i svenska privata trädgårdar och kombinerar trädgårdsinventeringar med studier av trädgårdsägares kunskaper, värderingar och skötselmetoder, i syfte att utveckla evidensbaserade riktlinjer för kommunikation med trädgårdsägare om invasiva arter. Metoderna som används varierar från fältinventeringar och expertworkshops till semistrukturerade intervjuer och en enkät som skickades ut till trädgårdsägare i tre områden med varierande bioklimatologiska förhållanden. Resultaten från trädgårdstudien visade att privata trädgårdar kan innehålla en stor artrikedom. De uppvisade en hög variation i artsammansättning och ingen korrelation mellan antalet invasiva arter och trädgårdens storlek. Enkäten, riktad till trädgårdsägare i de tre biosfärområdena Voxnadalen, Vänerskärgården med Kinnekulle och Blekinge arkipelag, visade på flera kunskapsluckor. Många av respondenterna kunde inte identifiera vanliga invasiva växtarter, och de flesta var osäkra på hur klimatförändringarna kan förväntas påverka invasiva arters spridning. Trädgårdsägare prioriterar estetik, härdighet, växtplatsens förutsättningar och stöd för biologisk mångfald framför växternas geografiska ursprung när de väljer växter till sina trädgårdar. Personliga erfarenheter av biodiversitetsförluster i deras omgivning som tillskrevs invasiva växter, ökade avsevärt sannolikheten för att ha vidtagit bekämpningsåtgärder mot invasiva arter i sin trädgård. Traditionella skötselmetoder som handrensning och grävning var vanligast förekommande och uppfattades som effektiva. Regionala skillnader i svaren underströk dessutom behovet av lokalt anpassad kommunikation. Resultaten möjliggjorde identifiering av evidensbaserade kommunikationsbehov som kan vägleda kommunikatörer på nationell, regional och lokal nivå i vilken information som bör ingå i deras budskap.

Keywords: invasiva främmande växter, privata trädgårdar, riskkommunikation, klimatförändring, hortikultur

Nomina si nescis, perit et cognitio rerum.

– Carl von Linné in Philosophia Botanica

To Gustav

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Palmér, C., Emilsson, T. & Blennow, K. Plant diversity and invasive species prevalence in Swedish domestic gardens (Manuscript)

II. Palmér, C., Wallin, A., Persson, J., Aronsson, M. & Blennow, K. (2023). Effective communications on invasive alien species: Identifying communication needs of Swedish domestic garden owners. *Journal of Environmental Management 340*, 117995. doi:https://doi.org/10.1016/j.jenvman.2023.117995

III. Palmér, C., Wallin, A., Persson, J. & Blennow, K. (2025). Horticultural practices of invasive plants: insights into priorities, awareness and management among garden owners. *Biological Invasions, 27*(11), 250. doi:10.1007/s10530-025-03705-2

All published papers are published open access.

The contribution of Cecilia Palmér to the papers included in this thesis was as follows:

I. Description of contribution to paper I. Conceptualisation, Formal analysis, Writing – original draft and editing

II. Description of contribution to paper II. Conceptualisation, Formal analysis, Writing – original draft and editing

III. Description of contribution to paper III. Conceptualisation, Formal analysis, Writing – original draft and editing

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Definitions

The thesis follows the definitions used in Swedish risk assessment (Strand et al. 2018) and international biodiversity frameworks (IUCN 2025):

Invasive alien species
"Invasive alien species are animals, plants or other organisms that are introduced by humans, either intentionally or accidentally, into places outside of their natural range, negatively impacting native biodiversity, ecosystem services or human economy and well-being." (IUCN 2025).

Alien species
A species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes or propagule of such species that might survive and subsequently reproduce (Convention on Biological Diversity). Sweden's risk assessment framework considers species alien if they were not naturalised in Swedish nature before the year 1800 (Strand et al. 2018).

Native species
A species that occurs naturally within its historical range in Sweden and has the capacity to reach and maintain populations without human assistance. In the Swedish context, this includes species that became established in Swedish nature before the year 1800 (Strand et al. 2018).

1.1 Background

1.1.1 Biological invasions and biodiversity

Biodiversity, with the variety of life at the genetic, species and ecosystem level, is important and provides essential services that human society depends on (Cardinale et al. 2012). This includes services such as pollination, nutrient cycling, climate regulation and cultural values (Mace et al. 2012). The ongoing loss of biodiversity is one of the most pressing environmental challenges of our time, with grave consequences for ecological stability and human well-being (Díaz et al. 2019).

The introduction and spread of invasive species have significant negative impacts on biodiversity (Bellard et al. 2013; Seebens et al. 2018), and it is commonly referred to as one of the major causes of species extinctions (Roy et al. 2024). Invasive species can outcompete native flora, disrupt ecosystem processes, alter habitats and reduce genetic diversity through hybridisation. Beyond ecological impacts, invasive species are associated with substantial costs through management effort, economic loss, negative effects on human health and impacts on ecosystem services (Kourantidou et al. 2022).

While invasive species pose a global threat to biodiversity, their impacts and dynamics vary considerably across different geographical regions and climatic conditions.

1.1.2 The Nordic context

The Nordic region faces a warming climate due to anthropogenic climate change (Rantanen et al. 2025). Climate change is expected to exacerbate the negative effects of invasive species, with the Nordic countries predicted to experience an increase in the number of invasive species in the coming decades (Bellard et al. 2013; Dullinger et al. 2017; Gallardo et al. 2017). Rising temperature, longer growing seasons, and milder winters are facilitating the establishment of alien species introduced to northern latitudes, removing climatic barriers that previously prevented their survival (Hellmann et al. 2008). Naturalised alien species are expanding their ranges polewards as conditions become more suitable (Zhang et al. 2023). This range expansion creates new opportunities for species previously confined to warmer regions to establish and spread in northern regions.

A Swedish national risk assessment predicts that approximately 250 terrestrial plant species are or can become invasive over the next half-century (Swedish Species Information Centre 2025a). A particular concern is that numerous ornamentals already present in gardens are currently grown outside their natural climate ranges, with low temperature preventing and restricting their spread (Haeuser et al. 2018). However, currently, only 15 terrestrial plant species relevant for the Swedish climate are prohibited from cultivation due to invasiveness under EU Regulation 1143/2014 (Swedish Environmental Agency 2025a).

There is a growing amount of research within the field of biological invasions. The majority of these studies are conducted in geographical locations that historically have had severe problems with invasive species, such as the USA, South Africa, Australia, Canada, India, Spain and the UK (Shackleton et al. 2019a). However, the Nordic countries present different ecological and climatic conexts that affect invasion risk. Sweden's geography ranges from maritime temperate zones in southern regions to subarctic in the north (Sjörs 1956), resulting in substantial variation in growing conditions and winter hardiness requirements, factors that differ markedly from warmer regions. Understanding invasion risks in the Nordic context requires understanding both the broader climatic and ecological conditions and the specific pathways through which alien species are introduced and spread. Gardens are an important pathway for the introduction of these plant species.

1.1.3 Domestic gardens

Gardening is a widespread and culturally significant activity in Sweden. More than 50 % of the Swedish population lives in detached houses, typically with private gardens (Statistics Sweden 2023), and a substantial proportion actively engages in gardening activities. It is the second most common outdoor activity after recreational walking (*promenader*). Residential gardens are one of the most common spaces for daily interaction with nature (Lerman and Warren 2011; Goddard et al. 2013). More than half of the population between 18 and 84 is interested in gardening, and 71% of those with access to a garden engage in gardening weekly (Björkman 2024). Domestic gardens are important spaces for daily interaction with nature,

providing opportunities to observe seasonal changes, and they can serve as expressions of personal identity and preserve cultural heritage through plants that carry stories and memories (Saltzman and Sjöholm 2016).

The benefits of domestic gardens extend beyond well-being. Private gardens contribute ecological value to urban and suburban landscapes. They provide habitat, support biodiversity, and enhance landscape connectivity (Tew et al. 2022). They contribute ecosystem services such as carbon sequestration, air purification, food security and stormwater regulation (Cameron et al. 2012).

While gardens and gardening can have many beneficial functions, horticulture and domestic gardens represent the main introduction pathway for alien terrestrial plant species in Europe (Hulme, 2018). Understanding this tension between the ecological benefits of gardens and their role as invasion pathway is essential for developing communication strategies that acknowledge gardeners' positive contributions while encouraging responsible plant selection and garden management.

Given a limited number of legally prohibited plant species (Swedish Environmental Agency 2025a), voluntary control measures and management of invasive plant species are key to preserving biodiversity. Garden owners form a strategic group to focus on since they are both potential introducers of invasive plants (Haeuser et al. 2018; Hulme et al. 2018) and potential allies in early detection and management (Dehnen-Schmutz & Conroy 2018; Shackleton et al. 2019a). Their knowledge level, practices and decision-making are crucial determinants of management in gardens (van Heezik et al. 2012). Given the central role of garden owners in both the introduction and management of invasive species, understanding what information they need about these species becomes very important.

1.1.4 Communication and knowledge

Effective management of invasive species in domestic gardens depends not only on scientific knowledge but also on garden owners' practical experience and local knowledge, and on how these different forms of knowledge are understood by garden owners (Cáceres-Escobar et al. 2019). Access to relevant scientific information enables both individuals and communities to make more informed decisions about environmental risks (Fischhoff 2013;

von Winterfeld 2013). Clear and accessible communication is essential for engaging gardeners in invasive species management (Vanderhoeven et al. 2011; Novoa et al. 2017). Yet current communication about invasive species is often one-directional, characterised by expert-to-public information rather than meaningful dialogue. This expert-to-public information approach fails to account for local perspectives, existing knowledge and practical realities of garden management. Moreover, laypeople may not intuitively understand the scientific rationale behind the invasive species control measures (Warner and Kinslow 2013), creating a gap between scientific recommendations and garden owners' actual practices. Developing evidence-based communication strategies that bridge this gap requires understanding what information garden owners need and how this information interacts with personal values and garden management practices.

Despite the crucial role of domestic gardens and garden owners in the management of invasive species, there is limited empirical knowledge about the actual occurrence of invasive species in Swedish gardens and how garden owners understand and manage these species.

1.2 Aim and research questions

Against this background, the overall aim of the thesis is to develop evidence-based guidelines for what information about invasive alien species needs to be communicated based on an empirical exploration of the Swedish garden flora and garden owners' knowledge and experiences of invasive alien species in private domestic gardens. To accomplish this, the following research questions were formulated:

1. What flora can be found in private domestic gardens, and what characterises the species pool of invasive alien plant species in southern Sweden? (*Paper I*)
2. What types of information do garden owners need to make informed decisions regarding invasive species in their gardens, and how do these information needs interact with personal values and garden management practices? (*Paper II and III*)

1.3 Structure of the thesis

The thesis consists of three papers addressing invasive species in private domestic gardens in Sweden. Paper I is arranged as a case study in Helsingborg, a coastal city in southern Sweden. It aims to provide background and context on the proportions and composition of how the floral composition in gardens can be structured. The paper explores the potential source pool of species for risk of invasion (Figure 1). Data collection and analysis were quantitative using methods commonly used in ecological research. Papers II and III were conducted using informing, qualitative methods to support a subsequent survey, which was used as the main source of data and analysed quantitatively. Papers II and III utilised data from the same survey based on answers from the respondents in the three biosphere reserves Voxnadalen, Lake Vänern Archipelago and Mount Kinnekulle, and Blekinge Archipelago. The focus of Paper II is the garden owners' knowledge, appreciation and personal experience of invasive species in their gardens and the surroundings, and Paper III focus on the respondents' plant preferences and garden management methods.

Figure 1. Structure of the thesis showing how the papers are interconnected. Paper I examines garden flora composition, Paper II investigates garden owners' knowledge and personal experience with invasive species, and Paper III explores their plant preferences and management methods. The results inform invasion risk and provide a base for evidence-based guidelines. Map adapted from Palmér et al. (2023).

1.4 Disciplinarity and project context

Interdisciplinary research integrates knowledge and methods from different academic disciplines to create a more comprehensive understanding than can be accomplished within any single discipline (Thorén and Persson 2013). Within invasion biology, this integration might involve combining insights from diverse areas such as horticultural expertise, ecological analyses, sociological investigations of behaviour, and psychological studies of risk perceptions (Vaz et al. 2017). Research on social perceptions of invasive species has been predominantly interdisciplinary, integrating ecological and social science perspectives to understand how different stakeholder groups perceive and respond to invasive species (Kapitza et al. 2019). Transdisciplinary research extends this integration beyond academic boundaries to include the co-production of knowledge with non-academic stakeholders (Brandt et al. 2013). It recognises that some fields, such as invasion biology, may require not only scientific expertise but also local knowledge and perspectives of those who directly interact with invasive plants, such as garden owners (Novoa et al. 2018). Sustainability solutions benefit from integrating scientific evidence with local knowledge, as place-based observations often expose dimensions that broader scientific approaches may not detect (Persson et al. 2018).

The dataset for Paper I was compiled during two projects aimed at investigating garden flora in the city of Helsingborg, Sweden. The first was a pilot study funded by Kungliga Skogs- och Lantbruks Akademin (the Royal Swedish Academy of Agriculture and Forestry). The second project was a collaboration with Helsingborg municipality, funded by Region Skånes Miljövårdsfond, and consisted of two main components: garden surveys and a communication initiative. The communication component included mailings to garden owners in the municipality, public lectures, an exhibition at garden fair and a blog focusing on enhancing biodiversity in gardens, including the avoidance of invasive species.

The project *Guidelines for effective communication with private domestic garden owners on Sweden's new risk classification of invasive alien species,* that Papers II and III are outcomes of, included researchers from different disciplines such as horticulture, landscape analysis, cognitive science, and philosophy and representatives from governmental organisations such as the

Swedish Environmental Protection Agency, the Swedish Species Information Centre and the Swedish Biosphere Reserve Coordinator. It was funded by Formas (grant number 2019–00165) and the project engaged representatives from local society in the three biosphere reserves Voxnadalen, Lake Vänern Archipelago and Mount Kinnekulle, and Blekinge Archipelago. The three biosphere reserves represented diverse bioclimatic conditions across Sweden. Biosphere reserves aim to promote sustainable development through living laboratories where local communities, governments and scientists collaborate (UNESCO 2024), making them particularly suitable areas for transdisciplinary research.

2. Central concepts and theoretical framework

2.1 Invasion biology

2.1.1 Risk in the context of biological invasions

Risk is a fundamental concept in invasion biology and plays a significant role in the policy and management of invasive species (Andersen et al. 2004). In general terms, risk can be understood as the combination of the likelihood of a negative event occurring and the magnitude of its consequences (Society for Risk Analysis 2018). In the context of biological invasions, risk encompasses the probability that a species will be introduced, established, spread and cause negative impacts, as well as the severity of those impacts on ecological, economic or social values (Andersen et al. 2004).

Three major components of risk analysis are: risk assessment, risk management and risk communication (Society for Risk Analysis 2018). Risk assessment is the technical/scientific process of evaluating the probability and magnitude of potential harm based on data and expert analysis (Andersen et al. 2004). Risk management involves determining what levels of risk are acceptable and what responses are appropriate, decisions that involve value judgment extending beyond scientific expertise (Aven 2016). Risk communication is the process of exchanging risk-related information among various target groups (Society for Risk Analysis 2018) and should facilitate informed decision-making by providing people with the information they need to understand the benefits, risks, and costs of their decisions (Fischhoff 2013). Risk assessment for invasive species in Sweden will be addressed in more detail in section 2.1.7, and risk communication in section 2.3.

2.1.2 The native-alien dichotomy

Categorising species as native or alien is central to invasion biology, yet it presents significant conceptual and practical challenges (Cassini 2020). Most definitions include three key components: (1) the dispersal of a species outside of its original distribution area, (2) human agency as a vector, and (3) a temporal point of reference (Richardson et al. 2011). The classification

of species as native or alien does not describe biological characteristics but is based on relative concepts of time, space, and human agency (Warren 2021). Geographical boundaries are pivotal when discussing native/alien categorisations, with national borders commonly used as reference points despite being political rather than biological boundaries (Antonsich 2021).

The temporal reference point used to define native and alien species varies considerably worldwide. In countries with colonial pasts, such as Australia, the temporal boundary was set before colonisation, specifically in 1788 (Richard and Trigger 2015). In the USA, the year 1492 is often referenced, based on European contact with the Americas (Antonsich 2021). In Sweden and Norway, the year 1800 serves as the reference point (Strand et al. 2018). None of these temporal references are based on the biological characteristics of species or recipient ecosystems but rather on cultural, historical, or political aspects (Antonsich 2021; Chew and Hamilton 2011).

The perception and management of invasive species are shaped by regional and cultural contexts (Selge et al. 2011a; García-Llorente et al. 2008). A significant proportion of publications on biological invasions originates from California, Australia, and South Africa (van Kleunen et al. 2018). In settler colonies, where entire landscapes were often replaced with introduced plants and landscape architecture, elements such as lawns are not merely contemporary landscape features but colonial environmental transformation (Mastnak et al. 2014). Consequently, gardening with native plants carries different cultural and ecological meanings in these regions compared to countries like Sweden (Mastnak et al. 2014).

At present, there is a lack of consensus on terminology for plants growing outside their natural distribution range. More than 25 different terms are used, often interchangeably, and laden with value judgments rather than ecological characteristics (Colautti and MacIsaac 2004). The most commonly used terms include 'alien,' 'non-native,' 'exotic,' and 'introduced' (Warren 2021).

One of the problems with using the native/alien categorisation as a binary concept is that the selection criteria for the categorisation can change. Uncertainty about current and historical distributions, as well as

anthropogenic influences such as changes in taxonomy and political changes regarding territorial borders, can alter the classification of a species rapidly (Warren 2021).

Climate change presents a fundamental challenge to traditional conceptions of native and alien species by altering environmental conditions and driving range shifts across taxa (Bellard et al. 2013). As temperature and precipitation patterns change, many species are expanding their ranges polewards and to higher elevations, creating new ecological communities without direct human intervention (Chen et al. 2011). The concepts of native and alien species remain central to invasion biology but face significant challenges in definition, application, and communication. Moving beyond binary classifications toward more nuanced approaches that consider ecological functions, impacts, and regional contexts may help bridge gaps between scientific understanding and public perception (Humair et al. 2014). As climate change continues to alter species distributions, traditional concepts of nativity may require further reconsideration (Pecl et al. 2017).

2.1.3 The invasion process: the introduction pathway

The introduction and establishment of alien species follow a hierarchical process where species pass through successive filters. Hellman et al. (2008) describe this process as beginning with the transportation of a species from one part of the world to another (Figure 2). By assisting the species in long-distance dispersal, the geographical barrier that naturally prohibits dispersal is overcome. The next phase is characterised by colonisation. If the species survives in the new habitat, the next barrier, abiotic conditions (e.g. low temperature), is overcome. In the establishment phase, the species acquires critical resources, survives interactions and also becomes adapted to biotic conditions. Finally, in the spread phase, species disperse across the landscape and become naturalised. When the species disperses prolifically and causes harm to the biodiversity and/or human well-being, it becomes invasive. This framework was further refined by Blackburn et al. (2011). Time from introduction to invasion varies between species and can sometimes take decades or centuries (Duncan 2011).

It's important to note that not all alien species become invasive. Most introduced species fail at one of the earlier barriers, with only a small proportion progressing through all stages to become invasive (Marsico et al. 2010).

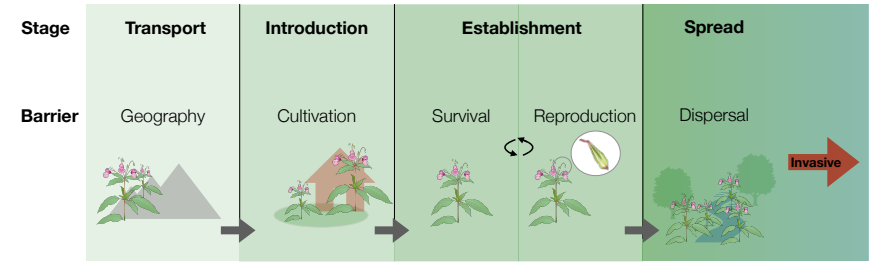

Figure 2. Invasion pathway illustrated by using *Impatiens glandulifera* in Sweden as an example. The species was transported from the western Himalaya and introduced to Europe as an ornamental garden plant in 1839, becoming naturalised in Sweden by 1918 and regulated under EU Regulation 1143/2014 since 2016. Adapted from ke et al. (2022).

2.1.4 Propagule pressure

Propagule pressure refers to the number of introduced organisms in an area and is a reliable predictor of establishment success in the introduced range (Lockwood et al. 2005). This concept encompasses both the number of introduction events (introduction effort) and the number of individuals released during each event (propagule size) (Blackburn et al. 2015). Propagule pressure is particularly significant for ornamental horticulture because of the prominent role of humans and their actions (Jeschke et al. 2022).

2.1.5 Invasion debt

The different stages in the introduction pathway can be linked to specific management and policy interventions, and this process has been described as an “invasion debt” (Essl et al. 2011). Invasion debt represents the additional amount of invasion that could occur in the future as a consequence of species already introduced or likely to be introduced. This debt can be divided and compartmentalised into different categories or sub-debts (Rouget et al. 2016) (Figure 3).

Introduction debt

This component quantifies the future invasion risk from species not yet present in an area but that are likely to be introduced (Rouget et al 2016). Management at this stage aims to identify species likely to become invasive if introduced, often through pre-border risk assessment, import regulations and pathway analysis (Hulme et al. 2008; Rouget et al. 2016; IPBES 2023).

Establishment debt

This concerns species already introduced but not yet naturalised. Management actions at this stage include early detection and rapid response protocols (Rouget et al. 2016). Risk assessment is a key tool for managing both introduction and establishment debt, allowing prioritisation of species for proactive control measures before they become widespread (Rouget et al. 2016; IPBES 2023).

Spread debt

This component addresses species that are established but have not yet reached their full potential range (Rouget et al 2016). Management actions at this stage include identifying priority areas for control, preventing further spread and determining where management actions are most needed (Rouget et al. 2016; IPBES 2023).

Impact debt

This concerns species already widely dispersed but whose impacts have not yet been fully realised or quantified. The purpose at this stage is to determine the ecological and economic cost of the invasion, assess cumulative impacts, conduct cost/benefit analyses and implement damage mitigation strategies (Rouget et al. 2016; IPBES 2023).

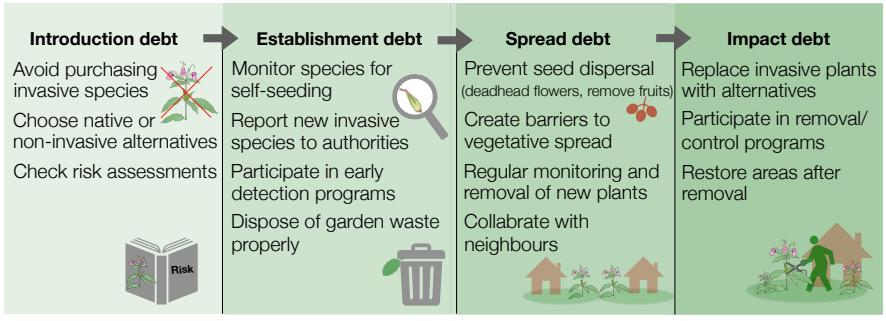

Figure 3. Examples of management actions available to private domestic garden owners corresponding to different components of invasion debt (practical applications adapted from Rouget et al. 2016). Action progresses from prevention (introduction debt) through early detection and rapid response (establishment debt) to control and restoration (spread and impact debt). The effectiveness of actions generally decreases from left to right while management costs increase.

At present, only species included in the EU regulation (1143/2014) of invasive alien species are prohibited from cultivation in Sweden due to invasiveness, though national legislation is pending (Swedish Environmental protection Agency 2025a). Hence, for most of the species assessed to be invasive in Sweden, no legal regulation exists, and thus, control measures are dependent on the voluntary management action of property owners. Preventive measures against invasive species are the most cost-effective management action and hence preferable (Rouget et al. 2016)

2.1.6 Invasiveness, invasibility and degree of invasion

Invasiveness refers to the intrinsic ability of an alien species to establish, spread, and cause impacts in new environments (Richardson et al. 2000). Unlike invasibility, which is a property of ecosystems, invasiveness is a species-specific trait that varies considerably among taxa. Invasiveness represents the capacity of a species to overcome various barriers to invasion, including geographical barriers, environmental conditions in the new range, reproductive limitations, and biotic resistance from resident communities (Pyšek and Richardson 2007).

Invasibility refers to the susceptibility of a community to invasion before an invasion event occurs (Guo et al. 2015). This concept should be distinguished from the degree of invasion, which measures the extent to which a

community has already been invaded. The key distinction is temporal: invasibility is assessed prior to invasion as a measure of potential vulnerability, while the degree of invasion quantifies the actual level of invasion that has already taken place (Guo et al. 2015).

The degree of invasion represents the actual extent of invasion in a community, typically measured as the absolute number, proportion, or biomass of non-native species (Guo et al. 2015). The degree of invasion reflects both the invasibility of the recipient community and the invasiveness of the introduced species, regulated by propagule pressure and environmental conditions (Catford et al. 2012). Highly invasible communities may show low invasion degrees if they have not been exposed to sufficient propagule pressure from potential invaders (Guo et al. 2015). Conversely, communities with low intrinsic invasibility may exhibit high invasion degrees if subjected to intense and persistent introduction pressure.

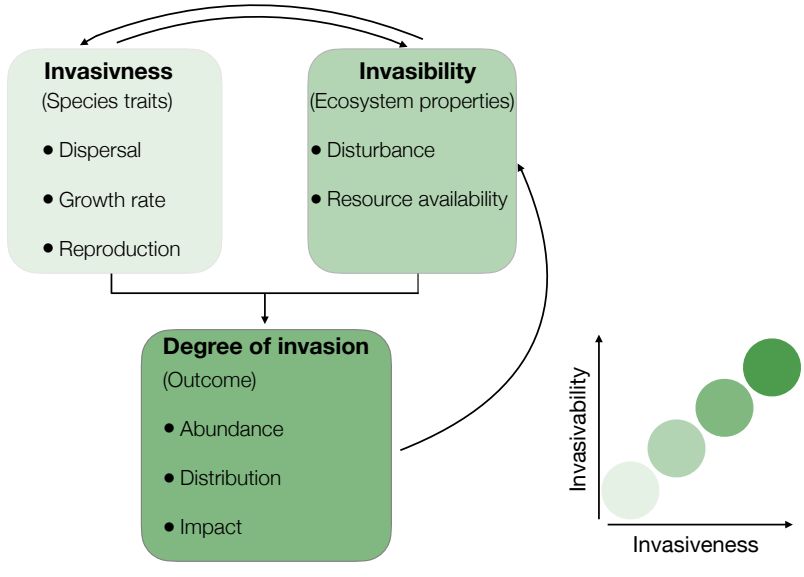

Figure 4. Conceptual illustration of the relationship between invasiveness, invasibility and the resulting degree of invasion. The feedback loops indicate that invasion outcomes can influence ecosystem invasibility, that traits in the plants can alter the recipient ecosystem and that the recipient ecosystem can select for traits in plants. The right plot illustrates how the degree of invasion is affected by invasiveness and invasibility. The degree of invasion gets darker green as the severity of invasiveness and invasibility increases.

Globally, patterns of invasion degree show substantial variation. Temperate islands and coastal mainland regions generally exhibit higher degrees of invasion than continental interiors or tropical regions (Pyšek et al. 2017). Human-modified landscapes, particularly urban and agricultural areas, consistently show elevated invasion levels (Gaertner et al. 2017).

The invasive potential of species varies significantly across different life forms, presenting unique management challenges (Pyšek and Richardson 2007). Woody plants (trees and shrubs) often have long lag phases before becoming invasive, but create persistent problems once established due to their longevity and structural impacts (Richardson and Rejmánek 2011). Herbaceous perennials can rapidly colonise disturbed areas through efficient vegetative reproduction (van Kleunen et al. 2018). Annual plants may spread quickly through prolific seed production and dispersal mechanisms (Moravcová et al. 2015)

2.1.7 Predicting invasiveness with risk assessment

Risk assessments for invasive species typically consider factors such as species traits, pathway characteristics, and receiving environment properties (Roy et al. 2018). The outcome of a risk assessment can guide decisions about which species to regulate, which pathways to monitor and where to allocate resources for prevention or control (McGeoch et al. 2016). There are at least 70 different risk assessment methods described and available for assessing potentially invasive species (Roy et al. 2018). The complexity of plant invasion due to intrinsic and extrinsic factors makes future invasions difficult to predict (Thuiller et al. 2006). Even experts within invasion biology disagree on opinions and terminology (Humair et al. 2014).

There have been several assessments of plant invasiveness in Sweden. Tyler et al. (2015) published a risk assessment of alien plant species in 2015. Subsequently, in 2018, the national Swedish risk assessment of invasive species was published (Strand et al. 2018). The Swedish Species Information Centre initially screened 3175 alien, vascular, terrestrial plant species using the Environmental Impact Classification for Alien Taxa (EICAT) method (Hawkins et al. 2015). Following this screening, they conducted a more detailed risk assessment of 605 alien plant species using the Generic Ecological Impact Assessments of Alien species (GEIAA) method (Sandvik

et al. 2013), which combines expert assessment with observational data (Strand et al. 2018). The assessment methods used to evaluate alien species' effects on Swedish biodiversity are applicable across various organism groups, which was a prerequisite for the national assessment. The evaluation incorporated predicted climate change scenarios for the next fifty years. In March 2025, an updated risk assessment was published, evaluating a total of 1012 vascular plant species (Swedish Species Information Centre 2025a). Of the assessed plants, approximately 250 plant species were categorised as having high impact or severe impact on biodiversity and were thus classified as invasive (Swedish Species Information Centre 2025a). These assessments, alongside EU regulation 1143/2014, now provide the main framework for identifying and managing invasive plants in Sweden.

2.1.8 Uncertainty within the discipline of biological invasions

Invasion biology is subject to several types of uncertainty (McGeoch et al. 2012; Humair et al. 2014; Latombe et al. 2019). For stakeholders such as gardeners, to make informed decisions, transparency about the limitations and uncertainties within the field is essential.

Epistemic uncertainty is uncertainty resulting from gaps in our knowledge and information. This could be due to reasons such as incomplete or limited data or methodological constraints (Regan et al. 2002). Importantly, it could be reduced with more and better data, improved methods or advances in scientific knowledge (Skinner et al. 2014). However, invasion biology also faces *aleatory uncertainty,* meaning that some aspects are inherently random or stochastic. This type of uncertainty arises from natural variability and unpredictable events such as extreme weather or random genetic mutations (Latombe et al. 2019). Unlike epistemic uncertainty, it cannot be reduced with more and better data because it represents randomness rather than knowledge gaps (Kiureghian and Ditlevsen 2009).

In addition, when species are involved, there is always a risk of *taxonomic uncertainty* (Pyšek et al. 2008). This includes challenges such as correctly identifying species and problems concerning hybridisation or taxonomic revisions (Pyšek et al. 2013). Moreover, the field is also exposed to *linguistic uncertainty* (McGeoch et al. 2012). This refers to ambiguities, vagueness and inconsistent use of terminology across different publications, regions and

stakeholder groups (Blackburn et al. 2011). Examples include the use and definitions of words like “alien”.

2.1.9 Ethical considerations within invasion biology

The discourse surrounding invasion biology has significant ethical and philosophical dimensions that extend beyond scientific considerations. Determining what species and genotypes to preserve and the alteration of ecological environments and systems are all connected to ethical implications (Hiernaux 2021). In the field of invasion biology, killing some species of plants, as well as animals, is often ethically justified, and it is generally accepted that some species are to be harmed or eradicated solely because of their origin, as well as the fact that humans translocated the species (Warren 2021). Notably, individual plants are often not valued, whereas we have a moral and legal responsibility to prioritise preserving entire groups – both species and ecosystems (Hiernaux 2021).

The terminology used in invasion biology, including words such as "alien", "invasive", and "exotic", is not value-neutral, and these linguistic choices embed implicit normative judgments that can influence management decisions and public perception (Larson 2005; Davis et al. 2011). Awareness of this linguistic dimension is important when interpreting and communicating research findings from this field.

2.2 Gardens as invasion pathways

2.2.1 Private domestic gardens in Sweden

Domestic gardens are an important arena for interaction with nature in urban areas. These everyday spaces are crucial sites where people engage with natural processes, observe seasonal change and experience the cycle of life (Saltzman and Sjöholm 2016). Gardens not only involve physical engagement with nature but also emotional connections to plants and the environment (Saltzman and Sjöholm 2019). Through these direct experiences, garden owners develop experiential knowledge that shapes their understanding of and responses to ecological processes, including management of invasive species (Dehnen-Schmutz and Conroy 2018).

More than half of the population in Sweden is estimated to live in a detached house (Statistics Sweden 2023), with garden sizes in urban areas typically ranging between 540 and 1120 m^2 (Bengtsson and Haller 2025). Interest in gardening has increased over the last five years, and particularly among people under 50 years (Björkman 2024). The role of domestic gardens has changed during the last century from cultivation of fruit and vegetables to gradually becoming a space for leisure and relaxation (Wilke 2014: Saltzman et al. 2016). Today, gardens serve multiple functions, from spaces for recreation and aesthetic enjoyment to sites for environmental engagement (Saltzman and Sjöholm 2016) and food production (Björkman 2024).

Despite their importance, gardens are not easy to access for researchers (Dehen-Schmutz 2018). Their private nature, combined with diversity in design and management practices, presents both challenges and opportunities for understanding human-nature relationships in everyday contexts (Saltzman and Sjöholm 2016). Nevertheless, the large, aggregated area that gardens make up and the autonomous status they hold make them important areas that should not be neglected (Qvenild et al. 2014).

Domestic gardens have been reported to contain a majority of alien plants (Cavender-Bares et al. 2020; Loram et al. 2008; Al-kofahi et al. 2024; Young et al. 2019; Marco et al. 2008; Wang et al. 2015). Ornamental plants used in gardens have great potential to survive in nature as they are often selected specifically for the climatic conditions on site and well-adapted to these environments. (Gederaas et al. 2012). Gardens comprise a mix of both cultivated ornamental plants and wild-growing species (Seitz et al. 2022), with Swedish domestic gardens self-reported to contain lawn, perennials, annuals, vegetables, shrubs and small trees (Björkman 2024).

Plant availability in domestic gardens is determined by the nursery industry and consumer demand, which influences what species are bought, planted, and cultivated. The traits favoured in horticultural selection often correlate with traits for invasiveness, such as vegetative growth and long flowering periods (Pyšek and Richardson 2007). However, some horticultural modifications reduce invasion risk. For example, double flowers, where petals replace reproductive structures, are often sterile and thus unable to produce seeds, limiting their ability to spread beyond cultivation.

The relationship between horticultural cultivation and invasion has been well established, and naturalisation of plants introduced for horticultural purposes has been well documented (Pyšek et al. 2010; Mayer et al. 2017; van Kleunen et al. 2018). Despite these concerns, even though a large proportion of the horticulturally available species are alien, most of them are neither considered invasive at present nor predicted to become so within the next fifty years (Stand et al. 2018; Swedish Species Information Centre 2025a; Jeschke and Pyšek 2018).

2.3 Understanding garden owners' decision-making

Effective communication about invasive species in domestic gardens requires understanding how garden owners make decisions and what information they need. The mental models approach provides a systematic framework for developing risk communication by identifying what people know and what they need to know (Morgan et al. 2002). Integrated with local knowledge, this approach can bridge the gap between expert knowledge and garden owners' practical decision-making contexts. Local knowledge refers to place-based, contextual understanding accumulated through direct engagement with specific environments and practices (Raymond et al. 2010). While risk considerations are an important component of decision-making about invasive species, garden owners' decisions also encompass broader considerations, such as aesthetic preferences, practical constraints, and cultural values.

2.3.1 Mental models approach

The mental models approach is built on the principle that adequate communication should fulfil two essential criteria: it should contain the information recipients need, and it should be presented in a form they can comprehend (Fischhoff 2013). This approach ideally encompasses the four key components, identifying science relevant to decision making, determining what people already know, designing communications to fill the critical gaps and evaluating their adequacy.

Identifying science relevant to decision making requires integrating knowledge from diverse scientific disciplines, including subject matter experts, decision scientists, and social and behavioural scientists. Rather than

providing comprehensive information from every relevant field, communicators should distinguish between what would be nice for people to know and what they need to know to make informed decisions (Fischhoff 2013). This process typically begins with a literature review to identify key factors, which are then organised into influence diagrams that visualise relationships between these factors. These preliminary diagrams undergo iterative refinement through panel discussion or semi-structured interviews with domain experts (Austin and Fischhoff 2012). Because decision-makers' priorities and understanding may evolve as they engage with new information, communication content must be adapted to remain relevant and appropriate for its recipients (Fischhoff 2013).

Determining what people already know involves interviewing laypeople to understand their language and beliefs, followed by broader surveys. The influence diagrams developed earlier provide the foundation for interview protocols designed to elicit laypeople's beliefs in their own vocabulary, after which the prevalence of beliefs identified during interviews is then assessed through structured surveys (Austin and Fischhoff 2012). This understanding is crucial when designing communications to fill critical gaps, as knowing the general knowledge level of laypeople provides limited guidance for effective communication. Instead, communicators should consider the specific mental models that decision-makers hold regarding the issue at hand (Fischhoff 2013).

Understanding what the intended audience needs to know to properly absorb the message is essential for adequate communication (de Bruin and Morgan 2019). To ensure adequacy and enable iterative improvements, one can evaluate communication effectiveness through methods such as think-aloud interviews, true/false questions, and problem-solving exercises (Austin and Fischhoff 2012; de Bruin and Bostrom 2013). Effective risk communication requires domain experts to ensure subject accuracy and behavioural experts to ensure comprehensibility (de Bruin and Morgan 2019).

2.3.2 Garden owners' knowledge, values and personal experience

Personal experience represents the individual's accumulated practical encounters that develop through hands-on engagement (Persson 2021). Through routine gardening tasks such as mowing, pruning, trimming and

weeding, garden owners become involved and develop practical knowledge through repeated interaction with their gardens (Saltzman et al. 2016).

Decision makers require knowledge in specific areas to make well-informed decisions concerning invasive species. The ability to identify species is central to invasive species management (Prinbeck et al. 2011; Balding and Williams 2016; Lindemann-Matthies 2016; Robinson et al. 2016; Jose et al. 2019). However, the lack of identification skills for invasive species among the general public has been reported in several parts of the world (Netherlands: Verbrugge et al. 2013; Portugal: Cordeiro et al. 2020; South Africa: Shackleton and Shackleton 2016; Colorado, USA: Daab and Flint 2010). The morphological characteristics of plants are highly variable, with intra-species variance as well as variation through different life stages and during the seasons (Sanders et al. 2022). Beyond identification skills, a lack of knowledge of what species are considered to be invasive among those who buy and manage invasive alien species in gardens has been reported (Shackleton and Shackleton 2016).

Garden owners' decision-making is strongly influenced by personal values and aesthetic preferences (Cavender-Bares et al. 2020). Preference for certain plant attributes frequently outweighs ecological concerns in gardening decision-making (Lindemann-Matthies and Brieger 2016). Garden owners have been reported to prioritise aesthetic qualities (flowering, colour), practical considerations such as maintenance requirements, hardiness and functional benefits such as shade provision and privacy screening (Van der Veken et al. 2008; Kendal et al. 2012). If invasive species are considered beautiful, people may be more willing to accept their detrimental aspects (Estévez et al. 2015).

Knowledge of the concept of invasive species is important (Verbrugge et al. 2013), yet laypeople and ecologists often have divergent perceptions of what makes a species invasive and problematic. While both groups focus on harmful impacts, ecologists emphasise non-nativeness whereas laypeople do not view geographical origin as inherently problematic (Selge et al. 2011a). Instead, laypeople are typically more concerned with observable plant traits such as colour, form, and cultivation qualities than with the origin of species (Qvenild et al. 2014). Selge et al. (2011a) found that the abundance of a

species and suppression of other species were the main characteristics perceived as problematic by laypeople, not the species' origin. Divergent perceptions also exist regarding which organism groups pose the greatest threat, with laypeople viewing animals as a larger threat while ecologists emphasise plants and their ability to disperse (Selge et al. 2011a).

Although certain species are classified as invasive due to their impact in natural areas, some gardeners do not perceive them as problematic as long as they remain within garden boundaries, a phenomenon known as ‘boundary maintenance’ (Shackleton et al. 2019b). This perception may partly reflect a lack of awareness among garden owners regarding the ecological impacts their cultivated plants can have beyond garden boundaries (Humair et al. 2014).

2.3.3 Communication framing and garden owner perspectives

Personal experiences, education, and media exposure collectively shape an individual's beliefs and understanding (Shackleton et al. 2019b), which in turn influences their capacity to distinguish between management approaches, such as proactive early detection versus long-term management strategies (Prinbeck et al. 2011).

Research on decision making demonstrates that the language and framing used can influence people’s preferences and choices (Wallin et al. 2016). Van der Wal et al. (2015) suggest that communication with the public should therefore focus on the specific reasons for species control, such as local ecology or impact on the economy, rather than emphasising origin as the primary motivator, as the general public may be more receptive to arguments based on observable impacts. The importance of this alignment is illustrated by Qvenild et al. (2014), who found that while Norwegian environmental authorities emphasised concepts like 'alien' and 'native' species, garden owners were primarily concerned with observable plant characteristics such as colour, shape, and invasive behaviour rather than classifications that cannot be directly detected in plants. This mismatch demonstrates how communication that fails to account for audience perspectives and priorities may prove ineffective.

2.3.4 Integrating scientific and stakeholder perspectives

Integrating local stakeholders' knowledge and perspectives, such as those of garden owners, could be beneficial for the success of management actions against invasive species (Cáceres-Escobar et al. 2019) and could increase acceptance of the control methods used (Bremner and Park 2007). Greater public participation would enable authorities to better understand local perspectives and preconceptions, facilitating more effective communication about planned interventions, underscoring the need for more deliberated and participatory communication strategies.

The mental models approach aligns with transdisciplinary principles by eliciting and analysing how different stakeholders perceive the risk of invasive species and using this understanding to develop more effective communication (Morgan et al. 2002). Through the integration of scientific and stakeholder knowledge, this approach bridges critical gaps between expert and laypeople perspectives (Fischhoff 2013). Employing the framework for risk communication, harnessing local knowledge and integrating it with scientific knowledge acknowledges garden owners' experience while addressing critical knowledge gaps related to invasive species management in private domestic gardens.

3. Research design

This thesis employed a mixed methods approach with embedded design (Creswell and Clark 2017), in which quantitative methods formed the primary framework while qualitative methods, such as interviews and influence diagrams, provided complementary insights that helped identify key themes and guided the development of a survey.

3.1 Data collection and analysis

3.1.1 Paper I

Case study

The gardens in Paper I were situated in the city of Helsingborg (Figure 4), among the ten largest cities in Sweden, where the relatively mild southern coastal climate supports diverse plant cultivation compared to northern Sweden. Since most problematic invasive species in Sweden first establish in southern Sweden and spread northward (Tyler et al. 2015), Helsingborg was found to be a suitable case study for examining garden flora with the potential to expand their range under warmer climate conditions.

Field surveys

Garden inventories in 48 gardens were performed during August in both 2015 and 2016. Plant identification was conducted at the species level for all material in cultivated borders, hedgerows and woody material. However, certain genera known for their vast array of horticultural hybrids and cultivars, such as *Rosa*, *Hosta* and *Rhododendron*, were documented only at the genus level.

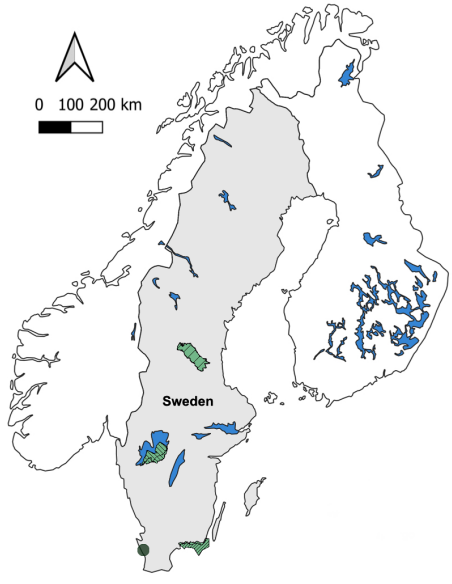

Figure 5. Location of Helsingborg (dark green circle) and the three biosphere reserves included in the study. Voxnadalen in the north, Lake Vänern Archipelago and Mount Kinnekulle in central Sweden and Blekinge Archipelago in the south. Adapted from Palmér et al. 2023. Made with Natural Earth.

Nomenclature, taxonomy and classification

Taxonomic nomenclature and species origin were validated using Artfakta (Swedish Species Information Centre 2025b). When horticultural taxa were absent from this primary source, the Swedish Utility and Cultivated Plants Database (2025) was used as an alternative reference. The definition of alien species followed Strand et al. (2018). Invasiveness status was determined by cross-referencing EU Regulation 1143/2014, Tyler et al. (2015) and the Swedish Species Information Centre (2025a), with species categorised as 'High Impact' or 'Severe Impact' classified as invasive. Life forms were classified in the categories *tree, shrub, herb, vine, grass, and fern* (Pierce et al. 2017). While genus-level identifications contributed to overall species richness estimates, they were omitted from the subsequent analyses examining origin, growth form and invasion risk, since these assessments depend on species-level taxonomy.

Spatial measurements of the gardens were derived from aerial imagery acquired in 2015 and 2016 and calculated using the open software QGIS (QGIS 2025).

Data analysis

The analysis for Paper I examined compositional patterns by calculating the proportional representation of different life forms, origin categories, and invasiveness classifications across gardens. Statistical tests compared the distributions and quantified compositional variation among gardens, and regression analyses explored relationships between garden characteristics and both overall species richness and the proportion of invasive species.

3.1.2 Paper II and III

Biosphere reserves

Biosphere reserves are areas that serve as learning sites for sustainable development, combining conservation with sustainable use of natural resources and research. They function as arenas for collaborations, connecting actors and promoting learning about sustainable development (Swedish Environmental Agency 2025b). In Papers II and III, the three biosphere reserves, Voxnadalen, Lake Vänern Archipelago and Mount Kinnekulle, and Blekinge Archipelago were used as study areas. These were purposefully selected to represent different bioclimatic conditions in Sweden, while also ensuring that they had representatives who could participate in the project.

Preparatory work

Following the mental models approach (Morgan et al. 2002; Fischhoff 2013) for risk communication, complemented by the Persson et al. (2018) framework for integrating local knowledge, several preparatory activities were conducted before the main data acquisition via survey.

A workshop was conducted with the participants in the project: the Swedish Environmental Protection Agency (Naturvårdsverket), Swedish Species Information Centre (Artdatabanken) and representatives from the three biosphere reserves. The purpose of the workshop was to identify priorities regarding invasive species in each specific context and determine the most problematic species to focus on throughout the project. During spring 2020,

a scoping literature review was conducted to examine the intersection between invasion biology and private domestic gardens in scientific literature. This review gave an orientation of what themes to focus on in the survey.

In summer 2020, 14 semi-structured interviews were conducted with garden owners across the three study areas. Participants were selected from each biosphere reserve to represent garden owners across three age groups (<35, 36-65, > 66), with an aim for gender balance. The selection included both those interested and not interested in gardening. Biosphere reserve coordinators provided contact information for potential interviewees through local personal networks and Facebook appeals, employing a snowball sampling technique (Atkinson and Flint 2001). Due to COVID-19 restrictions, all interviews were conducted by telephone. Participants were informed of the aim of the project, that their names would not be published, that the interview would be recorded and their right to withdraw without explanation.

The semi-structured interview protocol was developed based on the literature review findings and results from the workshop and focused on garden owners' knowledge, values and practices regarding invasive species. The interviews were recorded and summarised thematically. Influence diagrams are graphical decision-making tools that visually show decisions, uncertainties and outcomes and how these elements influence each other (Shachter 1986). To synthesise findings from the workshop, literature and interviews, influence diagrams were created. These diagrams helped identify key themes to address in the survey.

Survey

Based on the preparatory work, a survey was constructed and distributed through postal mail to approximately 2000 garden owners in each of the three biosphere reserves. Garden owners received the postal invitation with a link to the online survey tool Netigate (Netigate 2025). The cover letter informed the participants of the aim of the study, that the results would only be published in aggregated form and their right to withdraw at any time.

The survey explored the themes that emerged during the preparatory work relating to knowledge, such as knowing the definition of invasive alien species, the identification of species, and the dispersal of species. It also

addressed biodiversity, particularly the relationship between invasive species and biodiversity loss, as well as how climate change might impact the spread of invasive species. Finally, it also explored values, personal preferences and participants' level of appreciation for different invasive species.

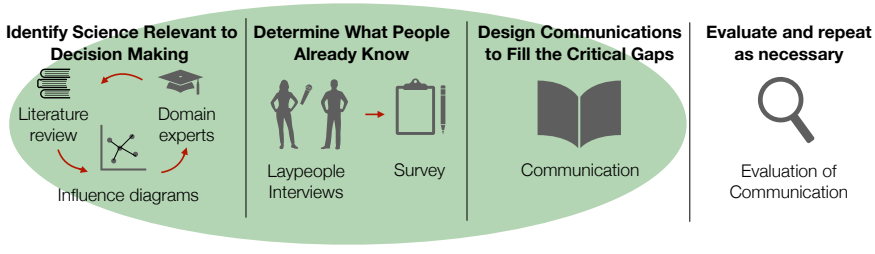

Figure 6. Visualisation of the work process for the preparatory work and subsequent survey. The green ellipse highlights the focus of activities in the PhD project. The description is a modified version, made by Palmér (2025), of the four phases in science communication described by Fischhoff (2013) and expanded by the mental models approach (Morgan et al. 2002).

Study species

The plants included in the survey in Papers II and III in the thesis were the five invasive plant species Himalayan balsam, *Impatiens glandulifera* Royle, garden lupin, *Lupinus polyphyllus* Lindl., Japanese knotweed, *Reynoutria japonica* Houtt., rugosa rose, *Rosa rugosa* Thunb., and lilac, *Syringa vulgaris* L. (Table 1). They were chosen because they all were introduced for ornamental gardening, represented different dispersal mechanisms, and ranged from being loved garden plants to being described as monsters in media coverage. *Reynoutria japonica*, *Rosa rugosa* and *Lupinus polyphyllus* have been mentioned as problematic species in the gardens, even though *Lupinus polyphyllus* was also valued and appreciated in some cases (Qvenild et al. 2014).

Table 1. Characteristics, ecological impacts and garden merit of five common invasive plant species in Sweden.

Name	Life form	Dispersal	Ecological impact	Garden merit
Impatiens glandulifera	Herbaceous annual	Seed, exploding	Dense stands that outcompete native vegetation, erosion, and rapid seed dispersal.	Large colourful flowers, prolific nectar source.
Lupinus polyphyllus	Herbaceous perennial	Seed, passive	Outcompetes native vegetation, alters soil nitrogen, dense monocultures.	Large colourful flowers.
Reynoutria japonica	Herbaceous perennial	Vegetative	Extreme growth outcompetes native vegetation, very difficult and expensive to control.	Large leaves, "exotic".
Rosa rugosa	Woody shrub	Vegetative, seed, bird	Dense thickets outcompete native vegetation, alter habitat structure.	Large colourful flowers, hips, nice scent, long flowering period, very hardy, used in plant breeding.
Syringa vulgaris	Woody shrub/tree	Vegetative, seed, passive	Dense thickets outcompete native vegetation.	Large colourful flowers, nice scent, cultural history.

Data analysis

For Paper II, the analysis employed machine learning methods to model complex non-linear relationships and interactions in the data, with variable importance assessed and non-significant variables systematically removed. Model performance was evaluated through cross-validation, and Bayesian methods were used to compare proportions across different respondent groups. For Paper III, the analysis employed non-parametric statistical methods appropriate for ordinal and categorical data. Differences in preferences and knowledge across groups were examined, correlation analyses assessed relationships between management method usage and

effectiveness, and tests of association examined connections between categorical variables.

3.1.3 Ethical considerations concerning data acquisition

According to guidelines from the Swedish Ethical Review Authority, ethical approval was not required as the survey was anonymous and did not collect sensitive personal data (Swedish Ethical Review Authority 2023). The survey cover letter informed the respondents on the aim of the study, the voluntary participation, how the results would be used, their right to discontinue at any time and that the results would be presented at the group level.

For the garden inventories, each garden owner was informed in writing a few days before visiting them, to also orally informed about the aim of the project, the voluntary participation, how the results would be used, and their right to discontinue at any time. If they wanted to participate, they subsequently signed a letter of consent giving permission to survey their property.

4. Summary of results

4.1 Garden flora and invasive species pool

The results from Paper I revealed a high plant diversity in the 48 domestic gardens surveyed, with 539 species identified (618 taxa), representing 85 plant families. Alien species dominated the gardens, with 68% of all species recorded. However, individual native species showed a broader distribution, occurring in 1.43 times more gardens on average than individual alien species. That the majority of species were alien is consistent with studies from a variety of garden surveys from different parts of the world (Cavender-Bares et al. 2020; Loram et al. 2008; Padullés Cubino et al. 2016; Al-kofahi et al. 2024; Marco et al. 2008; Ward and Amatangelo 2018). Among the alien species, 67 species (18%) had been classified as invasive or likely to become invasive in Sweden within the next 50 years (Swedish Species Information Centre 2025a). Notably, a risk assessment was unavailable for 192 plant species. Gardens with higher alien species richness also supported more native species. The composition of plant species varied considerably among gardens. Compositional uniqueness was not significantly associated with the proportion or number of invasive species. Garden size showed no significant relationship with total, native, alien or invasive species richness.

The findings from Paper I suggest that specific garden characteristics did not explain the plant diversity and compositions of gardens, indicating that garden owners themselves are important in understanding the flora of domestic gardens.

4.2 Knowledge gaps, values and management methods

Paper II identified species identification skills as a critical knowledge gap among Swedish domestic garden owners. Self-reported identification abilities showed significant limitations for some of the most common invasive species in Sweden. Garden owners reported difficulty identifying *Impatiens glandulifera*, *Reynoutria japonica* and *Rosa rugosa*, in particular, with identification rates varying substantially across the three study areas.

This is concerning given that accurate species identification is fundamental to effective invasive species management, reporting and communication.

A key finding from Paper II was that personal experience with biodiversity loss due to invasive species was a motivator for control action. Garden owners who attributed experienced biodiversity loss in the surrounding area to invasive species were significantly more likely to have taken control measures against invasive species. The importance of personal experience was also supported in Paper III, where it was found that personal experience with invasive species in their gardens also enhanced dispersal knowledge. For most of the included species (*Impatiens glandulifera*, *Reynoutria japonica*, *Rosa rugosa* and *Syringa vulgaris*), garden owners with personal experience of the species in their garden had better knowledge of how the species disperses than those without the species in their garden. The notable exception was *Lupinus polyphyllus*, where no significant difference was found between those with or without the species.

Having taken control measures against invasive species showed significant geographical variation in Paper II. Garden owners in the northernmost study area (Voxnadalen) were significantly more likely to have taken control measures against invasive species compared to the respondents in the two southern study areas (Lake Vänern Archipelago and Mount Kinnekulle, and Blekinge Archipelago). Approximately two-thirds of the northern respondents had taken action, while only a third of the southern respondents reported having done so. The survey data in Paper II also revealed that climate change impacts on invasive species were poorly understood among the garden owners. The majority of respondents (52-64% across study areas) expressed uncertainty about how climate change will influence invasive species. This knowledge gap represents a communication challenge, given the predicted increase in biological invasions in the Nordic region due to climate change.

In Paper III, practical cultivation qualities and biodiversity support consistently outranked the geographical origin of the plant in plant selection decisions. Garden owners reported a clear preference for functional plant characteristics such as morphology, hardiness, habitat suitability and nursery availability, as well as pollinator support and biodiversity benefits over both

Swedish and alien origin of the species, with alien origin receiving the lowest importance rating. Analysis of management practices in Paper III also showed that a positive correlation was found between the management methods used and their perceived effectiveness across all management methods included. Hand weeding and digging were the methods most frequently used and were also rated as highly effective. Chemical, thermal and salt-based methods were rarely used and generally perceived as less effective.

Paper III revealed a strong gardening interest was associated with better dispersal knowledge across all species. A geographical variation was found, with some species, such as *Reynoutria japonica*, being better known in the southernmost study area.

In summary, garden owners demonstrate significant knowledge gaps in species identification and climate change impacts and show practical management approaches grounded in personal experience. The geographical variation in knowledge and management, combined with the consistent prioritisation of practical cultivation characteristics over origin, indicates that communications would benefit from being locally adapted and aligned with garden owners' existing values.

5. Discussion

This thesis explores invasive species in Swedish domestic gardens by examining both the ecological composition of garden flora and garden owners' knowledge, values and management practices. The findings reveal knowledge gaps, important for risk communication and voluntary management efforts. These insights provide the empirical foundations for developing evidence-based guidelines on communication with garden owners about invasive species in their gardens.

5.1 Flora Composition and Species Pool

Paper I reveals a large number of species (539 species), even with a relatively small sample size of 48 gardens. The species accumulation curves showed no sign of saturation, indicating that the actual species pool of domestic gardens is considerably larger. This high diversity, combined with the finding that 38% of taxa were recorded once, demonstrates substantial compositional heterogeneity among gardens. Individual gardens are unique rather than replicates, possibly reflecting diverse aesthetic preferences, garden history and planting decisions of individual garden owners.

The majority of species found in domestic gardens in Sweden are alien, which is consistent with studies from several parts of the globe (Cavender-Bares et al. 2020; Loram et al. 2008; Al-kofahi et al. 2024; Young et al. 2019; Marco et al. 2008; Wang et al. 2015). However, while alien species dominated total species richness, individual native species occurred in more gardens on average. Garden owners collectively cultivated hundreds of different alien species, but each garden contained a unique subset of these. This pattern of common natives and diverse aliens has been observed in domestic gardens in the UK (Smith et al. 2006) and for street trees in ten cities in the Nordic countries as well (Sjöman et al. 2012).

Knowing which species can be found in gardens is important for identifying potential invasion risks and conducting risk assessments. This knowledge enables species-level assessment to detect traits associated with naturalisation success, such as longer residence time and dispersal mechanisms through wind and animals (Palit et al. 2024). Understanding

which species are present in gardens is also a prerequisite for evaluating their potential contribution to propagule pressure (Dehnen-Schmutz et al. 2007a), which is a key driver of invasion success (Lockwood et al. 2005; Cassey et al. 2018) Without such knowledge of which species are cultivated and how widely they occur across the domestic garden landscape, it is impossible to assess the cumulative risk these domestic gardens pose as a source of alien species to surrounding habitats. Paper I provide a first step in compiling a list of species actually present in Swedish domestic gardens, moving beyond assumptions about what might be cultivated.

However, assessing the invasibility of gardens (their susceptibility to invasion) is complicated by their nature as man-made and managed ecosystems. While gardens often exhibit characteristics associated with high invasibility, such as disturbance and high resource availability (Gioria et al. 2023), active management by garden owners can counteract these factors. Regular maintenance activities, such as weeding and selective cultivation, may suppress the establishment and spread of invasive species, meaning that inherent invasibility does not necessarily result in actual invasion. Moreover, the actual degree of invasion (the extent and impact of alien species establishment) requires additional data (such as abundance) beyond species presence.

Further investigation into the flora of domestic gardens should be prioritised to understand which species are widespread in gardens, present in high numbers and possess invasive traits in order to help focus assessment resources toward the species that pose the greatest potential threat. Long-term monitoring of garden compositions would also reveal temporal dynamics, such as which species are increasing in population, which are spreading spontaneously and how compositions change in response to climate warming.

Many of the alien species found in gardens (192 species) have not yet undergone standardised risk assessment. Domestic gardens are a private space where owners have the authority to make decisions on layout and species composition. In Sweden, where there is generally high confidence in public authorities (Rothstein and Stolle 2008), there may be unwarranted confidence that all risk species have already been assessed, leading to an

assumption that cultivating nursery-available species is inherently safe. However, a costly and time-consuming assessment process combined with a vast horticultural assortment available through global trade makes it difficult to keep pace with supply and horticultural innovation.

No correlation was found between the number of species and garden size. This result aligns with Cavendes-Bares et al. (2020) but is in contrast with Loram et al. (2008), who found a significant positive correlation between garden size and plant species richness across five cities in the UK. Similarly, no correlation was found between the number of invasive species and garden uniqueness.

Based on the hypotheses in Paper I, no biological or ecological explanation of the difference between gardens was found. Neither total species richness, compositional uniqueness, nor garden size predicted invasive species presence. This points to the role of garden owners' knowledge and values in determining garden compositions, factors examined in Papers II and III.

5.2 Decision Making and Influencing Factors

5.2.1 Knowledge gaps

Identifying invasive species

A fundamental finding is the lack of adequate identification skills among garden owners for some of the most common invasive species in Sweden. The practical implementation of voluntary management depends entirely on the public's ability to recognise invasive species in their gardens and in their surroundings. Consequently, this represents a critical barrier to effective management that has been underestimated in discussions concerning invasive species. Despite being among the most common invasive species, results from Paper II show that *Impatiens glandulifera* and *Reynoutria japonica* still had low identification rates. This inability to identify species is consistent with studies from South Africa (Seboko et al. 2024) and Switzerland (Lindemann-Matthies 2016).

The correlation between garden interest and improved identification ability found in Paper II suggests that botanical literacy could be enhanced through

targeted educational efforts. Garden owners reporting strong gardening interest consistently demonstrated better species identification skills and knowledge of dispersal mechanisms. However, it should be acknowledged that plant identification is complex, and plants often show morphological variability through seasons, life stages and genetic variability (Sanders et al. 2022). The phenomenon of plant blindness, the inability to see or notice plants in the environment (Wandersee and Schussler 2001), may also contribute to identification challenges.

Without improved identification abilities, many of the communication efforts about dispersal pathways and management techniques have a limited effect. Communicators should acknowledge that plant identification can be genuinely difficult and provide practical and accessible support, such as comprehensive visual guides.

The geographic variation in identification skills found in Paper II adds another layer of complexity. Different species may be more familiar in different regions depending on their prevalence and visibility in the landscape. *Lupinus polyphyllus*, for instance, was widely recognised in Voxnadalen where it is highly abundant and visible along roadsides, while *Reynoutria japonica* identification was better in Blekinge Archipelago. Communication materials would probably benefit from prioritising the species most relevant to local contexts.

Climate change and future risk

The Swedish national risk assessment takes into account climate projections for 50 years forward, recognising that species currently not invasive may become invasive as climate conditions become more favourable for their establishment and spread. However, the result from Paper II shows that most respondents did not know that climate change is predicted to affect invasion, revealing a knowledge gap between the expert community and garden owners that needs to be addressed in communications. It should be noted that half a century is a considerably long time frame for a garden owner making decisions about current plantings. This suggests that risk communication needs to bridge the gap between risk assessments spanning decades and the practical realities of garden management.

The geographic variation found in Paper III found that respondents in the northern study area (Voxnadalen), placed significantly higher importance on hardiness. As climate change expands the range of species that can survive northern winters, these garden owners may perceive increasing plant diversity as a benefit rather than a threat, being able to cultivate ornamental species previously restricted to southern regions. This creates a communication challenge, as the perceived horticultural benefits of climate change may overshadow concerns about increased invasion risks. Communications should therefore balance acknowledgement of expanded cultivation opportunities with clear information about the potential for the same species to escape and cause ecological harm.

It should be noted that the future climate is based on models and predictions, with inherent uncertainty about actual conditions. Natural migration of species needs to be considered, as well as the possibility that some alien species currently thriving in Sweden may prove valuable or even necessary under future climate conditions.

Understanding dispersal mechanisms

The plant species included in the postal survey cover different dispersal mechanisms, with some species root-suckering while others disperse via seed, passively, explosively or by birds. Garden owners with personal experience of species were significantly more aware of the dispersal pathways for *Impatiens glandulifera* (explosive seed pods), *Reynoutria japonica*, *Rosa rugosa* and *Syringa vulgaris*, the latter three root suckering. That an association was found for root suckering species is not surprising since the clonal dispersal is evident in the local context. In contrast, seed dispersal by wind and birds occurs over longer distances, often with variable offspring, making the dispersal source less apparent. The lack of association between garden presence and knowledge for the common *Lupinus polyphyllus* found in Paper III may reflect its widespread recognition among the population, as demonstrated by activities such as The Great Lupine Combat Day (Lagerqvist et al. 2024). This variation in knowledge supports findings that communication benefits from species-specific information.

5.2.2 What drives garden owner decisions

Plant selection priorities

Results from Paper III revealed that garden owners constantly prioritised plant characteristics such as aesthetics, hardiness, habitat suitability and biodiversity supporting abilities over geographical origin. For garden owners making practical decisions about what to plant, determining origin requires theoretical knowledge compared to observable traits in the plants. The results from Paper III, that origin was not considered important when choosing plants, align with Selge et al. (2011a, 2011b), who found that laypeople in Scotland, UK, focused on abundance and suppression of other species as problematic characteristics of invasive species, rather than origin *per se*. Similarly, Qvenild et al. (2014) found that gardeners in Norway frequently did not consider whether plants were native or alien, focusing instead on functional and aesthetic qualities.

Availability was considered important. The horticultural nursery industry is a key stakeholder when dealing with invasive species. The fact that a lot of horticultural species are showing detrimental effects on native biodiversity presents a growing challenge for disciplines like horticulture and landscape architecture. It is not easy to navigate the complexity of choosing plants. Often, the use of native plants is proposed, but this could also have implications for biodiversity. If non-locally native genotypes are chosen, introgression through hybridisation between cultivated or alien plants and natives can diminish genetic diversity (Bleeker et al. 2007).

Species appreciation

Many invasive species have beneficial qualities, but these are rarely systematically assessed alongside their negative impacts (Vimercati et al. 2020). Particular traits such as large colourful flowers and pleasant scent have made some species much more appreciated than others (Lindemann-Matthies and Bose 2007; Shackleton et al. 2019b). In Paper II, it was found that *Syringa vulgaris* and *Rosa rugosa* were appreciated species. These species share characteristics typically valued by gardeners, such as large showy flowers, pleasant fragrance and cultural associations with Swedish gardens. In contrast, the lack of appreciation for *Lupinus polyphyllus* was a significant factor in motivating taking control measures against invasive

species. These differential appreciations need to be acknowledged in communications concerning invasive species in gardens, as they can be a significant barrier to the voluntary removal of certain species. It might be tempting to provide lists of non-invasive alternatives with similar aesthetics rather than simply requesting removal. However, such lists risk overlooking key concepts in invasion biology. Propagule pressure could lead to overuse of recommended species, creating new invasions. Rather than relying on lists, communications should provide context-specific guidance tailored to local conditions.

Garden interest as a driver

Papers II and III revealed that garden owners very interested in gardening demonstrated higher levels of knowledge, such as better (self-reported) ability to identify invasive species and better understanding of dispersal mechanisms, and they were more likely to have taken management measures against invasive species. They ranked importance on habitat suitability and pollinator support as more important when choosing plants for their gardens, suggesting a more nuanced understanding of plant-environment interactions.

From a communication perspective, engaged gardeners represent both priority audience and potential champions. Gardeners as champions have been suggested as effective agents for promoting awareness and behaviour change in gardens (Goddard et al. 2013) However, it is crucial not to focus communication exclusively on already interested gardeners, but to employ different strategies for varying groups. While engaged gardeners may actively seek information and be receptive to complex messaging, less interested gardeners may require simpler, more accessible messages.

Regional variation

Respondents from Voxnadalen were more likely to have taken management actions against invasive species than respondents from Lake Vänern Archipelago and Mount Kinnekulle, and Blekinge Archipelago. Several factors may contribute to this geographic variation. First, *Lupinus polypyllus* is extremely abundant and highly visible in the landscape around Voxnadalen. This high visibility may make invasion impacts more apparent. Second, Voxnadalen is the northernmost study area with the coldest climate.

Respondents there placed significantly higher importance on plant hardiness. This may reflect experience with plant survival and cold tolerance. Third, local media coverage and local management initiatives, such as The Great Lupine Combat Day (Lagerqvist et al. 2024), may have differed between regions, resulting in varying levels of public awareness regarding invasive species management. The geographic variation in plant identification skills documented in Paper II also demonstrated regional differences, where *Reynoutria japonica* was better recognised in Blekinge.

The results in Papers II and III align with Verbrugge et al. (2013), emphasising that communication on invasive species should highlight regional context and provide species-specific information. Given the bioclimatic differences in a large country like Sweden, southern coastal garden owners face different invasion pressure and climate constraints than northern inland gardeners. The thesis fills a geographical gap in invasion biology research, which has been dominated by studies from Australia, India, Spain, the UK and the USA (Shackleton et al. 2019a). The Nordic context differs fundamentally from these regions, with a glacial history and large areas dominated by boreal forest ecosystems (Nota et al. 2022)

5.2.3 Management in practice

Management methods and effectiveness

Methods that were frequently used and reported as effective in Paper III were methods traditionally used in gardening, such as hand weeding and digging. Cutting was often used but not perceived as effective. That management methods such as covering the ground, which is a relatively cheap and easy way to manage invasive species when properly implemented (Martin et al. 2020; Dusz et al. 2021), are not as widely used may have several explanations. The limited space that gardens often exhibit means that closing off an area that must be covered for several years may be too much to sacrifice for gardeners who value their gardening space. One practical solution could be to cover the plastic membrane with some kind of mulch to enhance ornamental value and use the area for plantings in pots during the years of coverage. Other possible reasons for the limited use of covering methods may be hesitation to use plastic materials due to environmental

concerns about microplastic pollution, and the aesthetics of plastics in ornamental gardening or a lack of awareness that the method exists and can be effective when applied appropriately with sufficient duration. Thermal methods, such as hot water, are used in larger-scale management (Oliver et al. 2020; Blomqvist et al. 2024). However, they were rarely used by the respondents, who generally were uncertain of the method's effectiveness. This may reflect both limited access to the method and a lack of proper application. It may also be too expensive and unavailable for private gardeners to apply in their setting. The use of herbicides was reported to be low in Paper III and has probably become even less common since the survey was conducted. This is because when the survey was deployed in 2020, the legislation against the use of herbicides, such as glyphosate, was less restrictive (Regulation EU 2023/2660).

Furthermore, species-specific management recommendations are essential as the effectiveness of the technique for control differs between species. Hence, generic advice provides insufficient practical guidance for gardeners to successfully implement control measures. Examples of species-specific management methods are provided by the Swedish Environmental Agency's website on invasive species (Swedish Environmental Agency 2025c).

Invasion debt in gardens

Ornamental plants are often selected for climatic suitability, making them preadapted to local conditions (Gederaas et al. 2012). The lag phase between introduction and invasion, which can span decades or centuries (Hellman et al. 2008), means that current garden compositions can contain future invasions we have not yet identified. This creates a challenge for risk communication on invasive species directed at garden owners. The long time frame used in Swedish risk assessment exceeds most people's planning horizons for their gardens. A species that might become problematic by 2075 fails to compete against immediate garden design, habitat suitability and aesthetic preferences.

Different stages of invasion debt require different management approaches and information (Figure 3). The results from Papers II and III suggest that garden owners are most aware of 'spread debt' (visible invasion in surrounding areas) but may be less aware of 'introduction debt' and 'establishment debt', which their gardens represent. This disconnect is

concerning, given that the number of species found in all Swedish gardens is probably extensive, as indicated by the accumulation curves in Paper I. Almost 200 species were found that have not yet been risk assessed, suggesting that the invasion debt may be considerable.

5.2.4 Challenges for communication and decision-making

Personal experience versus predictions

There may be some important limitations when trying to integrate the experience of garden owners into risk communication, as personal experience may represent both an opportunity and a challenge in invasive species communication. As reported in Paper III, garden owners who had the invasive species in their garden were more likely to know how the species spread. Moreover, direct experience with biodiversity loss due to invasive species emerged as a significant motivator for taking management measures against invasive species in their garden. Thus, personal experience may contribute to increased knowledge and more proactive behaviour against invasive species. However, personal experience may also be problematic when it contradicts expert assessments and future predictions. If a garden owner has personal experience of a species not being problematic, for instance, cultivating *Rosa rugosa* for decades without observing spontaneous spread, it could be difficult to convince them to remove the species based solely on expert predictions that it may become problematic within the next fifty years. Several factors may complicate this challenge. First, the gardener may have misidentified the species or may be unaware of spread occurring beyond their immediate observation range. Second, climate change may fundamentally alter a species' behaviour, rendering decades of stable local experience unreliable for predicting future events. The temporal mismatch between personal garden experience (measured in years to decades) and invasion dynamics (potentially spanning centuries with long lag phases) creates a particular challenge. A gardener who has successfully contained a species for a long time may reasonably question warnings about future invasiveness, especially when the timeframe extends beyond their own life expectancy or garden ownership period.

Furthermore, the fragmented ownership of gardens means that individual garden owners may lack awareness of cumulative propagule pressure. While one person's *Rosa rugosa* may appear contained, the collective presence of this species across hundreds of gardens creates a landscape-scale propagule pressure that no single gardener directly observes. For species with long-distance dispersal by wind or birds, it may be additionally difficult to connect one's garden plant with impacts in distant natural areas that the gardener may never visit.

There are inherent limitations to personal experience in the context of rapidly changing environmental conditions and complex landscape-scale ecological processes. The results from Paper II and III show that personal experience is important in invasive species decision-making, but relying on it may lead to unwarranted confidence from temporally and spatially limited observations, resulting in an underestimation of climate change impacts on familiar species. Communication strategies should therefore find ways to make future and distant impacts more tangible in the present.

Voluntary action and private property

It is important to ensure garden owners make an informed decision while acknowledging that complete information may never be available. This tension between the precautionary principle (acting to prevent harm under uncertainty (Kriebel et al. 2001) and respect for individual autonomy (allowing personal choice in private property management) fundamentally shapes the challenge of domestic garden invasive management.

Currently, approximately 250 plant species are assessed to be or become invasive within the next fifty years, yet only a small number are legally prohibited under EU Regulation 1143/2014 and the pending Swedish legislation. The vast majority of assessed species remain legally available for purchase and cultivation. Avoiding these species or taking management measures against them involves entirely voluntary action by garden owners, who must sacrifice plants they may value and have invested in.

How much responsibility can reasonably be expected of garden owners? On one hand, gardens constitute 10-20 % of urban areas in Sweden (Bengtsson and Haller 2025) and serve as a major propagule source for invasive species.

Garden owners collectively have a large impact on landscape-scale invasion dynamics. Their individual decisions aggregate to create conditions for, or barriers against, biological invasions. From this perspective, there is a public interest in garden management decisions that extend beyond property rights. On the other hand, domestic gardens are private property over which owners exercise substantial autonomy. Gardens reflect individual aesthetic preferences, cultural traditions and emotional as well as economic investments. Asking someone to remove a rose bush planted by a loved parent or a lilac hedge marking a property boundary for many years implicates values beyond ecological risk assessment.

In the context of invasive species in domestic gardens, experts can assess ecological risks using biological data and climate projections, but determining how society should respond to these risks, through legislation, voluntary actions, public education, or trade regulations, requires democratic deliberation about acceptable trade-offs between environmental protection, property rights, individual autonomy and cultural values.

5.3 Guidelines for communication

Based on the research findings and in response to the thesis aim of developing evidence-based communication guidelines, the following recommendations address the key knowledge gaps, values and practical realities identified among Swedish garden owners. Communication on invasive species to domestic garden owners will likely benefit from:

- **Species Identification Support**. Provide comprehensive visual guides showing plants across seasons and life stages. Include how the species are dispersed and that long-distance dispersal can be hard to detect.
- **Regional adaptation of communication**. Acknowledge bioclimatic differences and account for regional differences in gardening conditions and species behaviour. Reference familiar local examples in invasion impacts.
- **Address climate change explicitly**. Explain how climate change may alter familiar species' behaviour. Make long-term predictions (e.g. 50-year assessments) relevant to current

decision-making by explaining how climate change is predicted to enable previously marginal species to become invasive.

- **Bridge personal experience with expert knowledge**. Help gardeners understand cumulative propagule pressure beyond individual gardens by making future and distant impacts tangible through local examples.
- **Provide species-specific practical management guidance**. Explain management methods and include realistic timeframes. Offer instructions for control methods that work for each species or group of similarly managed species.
- **Acknowledge differential appreciation**. Connect invasive species management to valued outcomes like biodiversity support. Do not rely solely on native/alien framing. Recognise that some invasive species are valued and that communication needs to be adapted to different appreciation levels.
- **Segment garden interest**. For less interested garden owners, use simpler messages through channels they already access. For domestic garden owners with extensive garden interest, complement by providing more detailed information and use champions, if available.
- **Present information transparently**. Communicate both scientific findings and their limitations openly, including uncertainty in risk assessments and climate projections.

5.4 Potential bias and limitations

5.4.1 Garden inventory

The neighbourhoods for garden inventories were strategically selected to cover gardens from diverse historical periods and to include spatially connected areas, with every second garden chosen for survey. However, the requirement for informed consent introduced potential self-selection bias, where participants who agreed to participate may have differed from those who declined. Nonetheless, very few participants declined, and the results included a wide range of different gardens with varying species richness, making this bias less likely.

Furthermore, as a case study conducted in a single Swedish city, the geographical scope limits generalisability. Garden floras show high compositional variation even at local scales (Thompson et al. 2003), and Sweden has substantial bioclimatic variation (Sjörs 1956), suggesting that regional context may be crucial for understanding garden flora composition However, the aim of the study was not to characterise the entire Swedish garden flora, but rather to document the potential species pool present in urban gardens. The actual number of species is expected to be considerably larger, as seen in the accumulation curves that failed to reach an asymptote.

Challenges in taxonomic identification during the inventory for Paper I may have introduced classification errors into the dataset (Bortolus 2008). Misidentification of certain individuals to the species level may affect the precision of the analyses. This limitation is particularly relevant for ornamental taxa, where cultivation variation, hybridisation and morphological plasticity can complicate identification (Dehnen-Schmutz et al. 2007b). To minimise identification errors, photographs were taken of plants difficult to identify in the field and subsequently cross-checked with other horticultural expertise within the Swedish University of Agricultural Sciences. Despite these quality control measures, some degree of taxonomic uncertainty may remain.

5.4.2 Postal survey

Response bias in the postal survey may have affected the postal survey. Although addresses were randomly sampled within municipalities in the three biosphere reserves, garden owners with greater interest in plants, gardening or biological invasion may have been more inclined to respond. A substantial proportion of respondents reported knowing the definition of invasive species, and the average age was relatively high. However, it should be noted that garden ownership in Malmö was 58 years, and the mean duration of residence at the property was almost 20 years (Klobucar et al. 2021), partially mitigating concerns about age-related bias. Social desirability bias may have led respondents to provide responses they perceive as more acceptable rather than genuine views (Krumpal 2013). In addition, question order may affect responses (Tourangeau et al. 2000). This was avoided by a function that randomly ordered the sub-questions and species names when possible in the survey. Reliance on self-reported data also has inherent limitations regarding accuracy and validity. The gap between reported intentions and actual behaviour is well-documented (Sheeran and Webb 2016). Self-reported knowledge cannot be independently verified in this study.

Both the garden inventory and the postal survey were conducted as single-time studies. The data, therefore, represent a temporal snapshot of species compositions, conditions, knowledge levels and perceptions at one specific point in time.

5.4.3 Statistical and predictive uncertainty.

Beyond the uncertainties inherent in climatic predictions and risk assessments of invasive species, the studies may have uncertainty stemming from sampling and measurement errors. Confidence intervals, Bayesian credible intervals and significance levels are reported to communicate statistical uncertainty. Supplementary material containing test statistics has been published alongside Papers II and III to ensure transparency.

6. Conclusion

This thesis explored the role of Swedish domestic gardens in the invasion process by investigating both garden flora composition and garden owner knowledge, values and management practices to inform evidence-based guidelines for communication.

The garden inventories revealed that Swedish domestic gardens harbour high species diversity with alien species dominating the overall species pool, though individual native species occurred more frequently across gardens. Gardens contained numerous invasive species along with many alien species not yet risk-assessed, representing a potential invasion debt.

No correlation was found for garden size and proportion of invasive species, and the compositional heterogeneity among gardens demonstrates that individual gardens are unique assemblages rather than replicates. This diversity may reflect the individual garden owners whose knowledge, values and management decisions determine which species are cultivated or removed rather than garden characteristics such as size.

Species identification emerged as a critical barrier to voluntary management. Substantial proportions of respondents could not identify some of the most common invasive species in Sweden, such as *Impatiens glandulifera* and *Reynoutria japonica*. This identification gap undermines subsequent communications about dispersal mechanisms and management techniques. The majority of respondents were also uncertain about how climate change is predicted to affect the spread of invasive species, revealing a significant knowledge gap between expert assessment and garden owner understanding.

Garden owners prioritised cultivation qualities such as aesthetics, hardiness, habitat suitability and biodiversity support over geographical origin of the plant species when selecting plants for their gardens. This indicates that communications emphasising origin alone are unlikely to influence plant selection, instead, communication would benefit from connecting invasion risk to qualities garden owners value, such as biodiversity support. Those who had experienced biodiversity loss and who had attributed this loss to

invasive species were significantly more likely to have taken control measures against invasive species in their gardens.

A geographical variation was found for multiple findings, including species identification rates, proportions that had taken control measures against invasive species, and differences in priorities when choosing plants for their gardens. These regional differences underscore the need for communication strategies that prioritise locally relevant species, provide local examples, and acknowledge bioclimatic variation. Management practices revealed pragmatic patterns with garden owners using traditional techniques like hand weeding and digging that they perceived as effective based on personal experience. Methods using hot water, salt or herbicides were rarely used.

Based on these findings, this thesis provides evidence-based communication guidelines that address critical knowledge gaps and needs, such as identification barriers, species-specific information, regional variation, and temporal scales mismatches between personal experience and long-term predictions.

These findings demonstrate that effective management of invasive species in domestic gardens depends on communication strategies grounded in both scientific evidence and understanding of garden owners' existing practical knowledge and experience.

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Popular science summary

Invasive alien species are organisms introduced by humans that harm native biodiversity, and they represent one of the major threats to biodiversity worldwide. The problem with invasive species is expected to become worse with climate change, particularly in the northern regions of the world. Many of these species that become problematic are originally introduced through horticulture and cultivation in domestic gardens, which collectively cover substantial urban areas. Individual planting and management decisions aggregate to shape a large-scale garden landscape, yet individual garden owners rarely perceive this cumulative impact. This thesis investigates what grows in Swedish domestic gardens and what garden owners know about invasive plants. Garden inventories revealed high plant diversity, with the majority of species originating from other countries. The postal survey of garden owners across three study areas, from northern Voxnadalen to central Lake Vänern Archipelago and Mount Kinnekulle, and southern Blekinge, revealed several knowledge gaps and communication needs. Many of the respondents reported not being able to identify common invasive plant species like Himalayan balsam and Japanese knotweed, and most were uncertain of how climate change is expected to impact invasive species. Garden owners prioritise aesthetics, hardiness, habitat suitability and biodiversity support over the plants' geographical origin when selecting plants for their gardens. Personal experience of biodiversity loss in their surroundings attributed to invasive species significantly increased the likelihood of having taken management measures against invasive species. Traditional management methods like hand weeding and digging were most commonly used and perceived as effective. In addition, regional differences in responses highlighted the need for locally adapted communication. The thesis provides practical guidelines for communication with garden owners about invasive species, recognising that effective management depends on bridging scientific knowledge with the practical realities and values of garden owners.

Populärvetenskaplig sammanfattning

Invasiva främmande arter är organismer som har introducerats av människor och som skadar den inhemska biologiska mångfalden. De utgör ett av de största hoten mot biologisk mångfald globalt. Problemet med invasiva arter förväntas förvärras i takt med klimatförändringarna, särskilt i de norra delarna av världen. Många av de arter som blir problematiska har ursprungligen introducerats genom trädgårdsodling och användning i privata trädgårdar, vilka sammantaget täcker stora urbana ytor. Trädgårdsägares planterings-och skötselval i den enskilda trädgården formar tillsammans ett landskap av trädgårdar i stor skala, men det är svårt för enskilda trädgårdsägare att uppfatta denna samlade påverkan. Denna avhandling undersöker vad som växer i svenska privata trädgårdar och vad trädgårdsägare vet om invasiva växter. Inventeringar av trädgårdar visade på en hög artdiversitet, där majoriteten av arterna ursprungligen kom från andra länder. En enkät till trädgårdsägare i de tre studieområdena, Voxnadalen, Vänerskärgården med Kinnekulle och Blekinge arkipelag, avslöjade flera kunskapsluckor och kommunikationsbehov. Många av respondenterna uppgav att de inte kunde identifiera vanliga invasiva växtarter som jättebalsamin och parkslide, och de flesta var osäkra på hur klimatförändringarna förväntas påverka invasiva arter. Trädgårdsägare prioriterar växtens utseende, härdighet, lämplighet för växtplatsen och stöd för biologisk mångfald framför växternas geografiska ursprung när de väljer växter till sina trädgårdar. Personliga erfarenheter av förlust av biologisk mångfald i närområdet som tillskrevs invasiva arter ökade signifikant sannolikheten för att trädgårdsägarna hade bekämpat invasiva arter i sin trädgård. Traditionella skötselmetoder som handrensning och grävning var vanligast förekommande och uppfattades som effektiva. Dessutom visade regionala skillnader i enkätsvaren på behovet av lokalt anpassad kommunikation. Avhandlingen ger praktiska riktlinjer för kommunikation med trädgårdsägare om invasiva arter och betonar att effektiv hantering av invasiva växter handlar om att förena vetenskaplig kunskap med de praktiska realiteter och värderingar som finns hos svenska trädgårdsägare.

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II

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Research article

Effective communications on invasive alien species: Identifying communication needs of Swedish domestic garden owners

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ABSTRACT

Invasive alien species threaten biodiversity with domestic gardens acting as a major pathway for the introduction of alien species. Even though the Nordic region is not currently a hotspot for biological invasions, the number of invasions in the Nordic area has been predicted to increase due to climate change. Given a time lag between introduction and invasion, many non-invasive horticultural alien species already introduced into gardens may become invasive in the future. This study aimed to identify the communication needs of Swedish garden owners regarding their management of invasive alien species. A survey among domestic garden owners, informed by topic specialists and local area experts, and interviews with garden owners were conducted in three different bioclimatic areas in a latitudinal gradient across Sweden. The questions targeted invasive alien species and their relations to biodiversity loss and climate change, as well as measures taken to control these species. Analysing the survey data collected in relation to measures taken to control invasive species, Bayesian Additive Regression Tree (BART) modelling was used to identify geographically varying communication needs of the domestic garden owners. In all study areas, the garden owners' measures taken to control invasive alien species were correlated with their strength of beliefs in having experienced local biodiversity loss. A majority of the garden owners were, moreover, uncertain about the impact of climate change on the invasiveness of alien species. In addition, the garden owners' capacity for identifying invasive alien species was often in need of improvement, in particular with respect to the species *Impatiens glandulifera*, *Reynoutria japonica* and *Rosa rugosa*. The results suggest that the evidence-based guidelines for effective communications we developed, have the potential to help communicators meet the local communication needs of garden owners across Sweden, in relation to the management of invasive alien garden species.

1. Introduction

Invasive alien species (IAS) pose a threat to biodiversity for several reasons such as competing for resources and as a major cause of ecosystem degradation (Pyšek and Richardson, 2010; Simberloff et al., 2013). According to Hulme et al. (2018), horticulture is the main pathway for the introduction of terrestrial invasive plant species. The range of horticultural species and varieties is large and increasing (Bradley et al., 2012; van Kleunen et al., 2018). Alien plants generally outnumber native plants in domestic gardens (Loram et al., 2008; Mayer et al., 2017) making domestic gardens a major pathway for introduction of alien species worldwide (Dehnen-Schmutz and Conroy, 2018).

Given a time-lag between the introduction of a species and the invasion phase (invasion debt) (Essl et al., 2011; Rouget et al., 2016), a large number of horticultural species already introduced, but currently not invasive, may become invasive in the future (Mayer et al., 2017; Haeuser et al., 2018).

In the Nordic region, which is not currently a hotspot for biological invasions, the number of invasions is predicted to increase due to climate change (Bellard et al., 2013; Dullinger et al., 2017; Gallardo et al., 2017). This is partly because of invasion debt but also because, with climate change, horticulture is predicted to assist alien species' migration (Van der Veken et al., 2008).

The Nordic country of Sweden is one of the largest countries in the

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EU, covering 41 million hectares (Statistics Sweden, 2022) and an extensive biogeographic range (Bevanger, 2021). In Sweden, 85% of the citizens live in urban areas and more than half (52%) of the population (10,5 million citizens) live in detached houses (Statistics Sweden, 2021). Norrland, in the north of Sweden, occupies more than half of the country's area but is inhibited by only 11% of the population. Most of the introduced alien species originate from Europe, Asia and North America (Weidema, 2000). To estimate how many plants are invasive in Sweden, 3175 alien plant species were screened for invasiveness (Strand et al., 2018) using the Environmental Impact Classification for Alien Taxa method (see Hawkins et al., 2015). Of these, the 585 most critical species were chosen for a more thorough risk assessment using the Generic Ecological Impact Assessment of Alien Species method (Version 3.3) (see Sandvik et al., 2017) of which 115 alien species were categorized as invasive (Strand et al., 2018). Notably, the majority of invasive plant species were observed in the southern part of the country, where the human population density is higher (Artportalen, 2023). The recorded costs for the control of IAS in Sweden between 1960 and 2021 was estimated to $1.45 billion (Kourantidou et al., 2022).

Informed and motivated citizens can have an important role in IAS management (Marchante and Marchante, 2016) and several projects drawing on citizen science are active in Europe (Sweden: Artfakta, 2023a; Britain and Ireland: Plant alert, 2023). At present, studies targeting stakeholder involvement in the Nordic countries are underrepresented. However, examples from other parts of Europe provide valuable input to the development of country-specific guidelines for the Nordic countries. The general public's familiarity with the concept of IAS (Verbrugge 2013; Junge et al., 2019), the ability to correctly identify IAS morphologically (Lindemann-Matthies, 2016) and the knowledge of which plants are invasive (Shackleton and Shackleton, 2016), have been found to be important for the public's support for IAS control efforts. In addition, implementing a code of conduct can inform the public and limit the number of IAS available in the nursery trade (Heywood and Brunel, 2011). A need for communication with garden owners on the issue of the threat of IAS and the prevention of further dispersal has been acknowledged (Tyler et al., 2015; Dullinger et al., 2017). However, it has been emphasised that targeted campaigns aimed at specific groups are needed to reach the intended groups (Halford et al., 2014; Potgieter et al., 2019) and to be successful, a long-time perspective and commitment are necessary (Verbrugge et al., 2014). Whether the plants are considered beautiful and desirable or not can influence garden owners' willingness to remove the species from their gardens (Shackleton and Shackleton, 2016). This factor can complicate communications. Finding a plant beautiful can mean that detrimental aspects of the species may be accepted (Lindemann-Matthies, 2016) but diminishing sense of the beauty with new knowledge on the invasiveness of the species has also been reported (Cordeiro, 2020).

As a first step in a process to develop evidence-based guidelines for communications on IAS, what Swedish domestic garden owners need to know in relation to IAS was identified in consultations with a group of topic specialists. This mapping of causal relationships was supported by a literature overview and was followed by explorative interviews with garden owners in order to ensure that relevant aspects of garden owners' experience and knowledge relating to IAS were taken into account. Based on this preparatory work, the following hypotheses were formulated and tested.

H1: The strength by which garden owners believe that they have experienced local biodiversity loss due to invasive species correlates positively with measures taken to control invasive species in their gardens (cf. Niemiec et al., 2016)
H2: The strength by which garden owners believe in the impact of climate change on the invasiveness of invasive species correlates positively with measures taken to control invasive species in their gardens (cf. Bardsley and Edwards-Jones, 2007)
H3: The strength of appreciation of a specific plant species correlates negatively with measures taken to control invasive plant species (cf. Qvenild et al., 2014; Lindemann-Matthies, 2016)

The strength of Swedish garden owners' appreciation of the invasive alien species (3a) *Impatiens glandulifera*, (3 b) *Lupinus polyphyllus*, (3c) *Reynoutria japonica*, (3 d) *Rosa rugosa* and (3e) *Syringa vulgaris* correlates negatively with measures taken to control invasive alien plants in their gardens.

2. Method

2.1. Study areas

The three biosphere reserve areas Voxnadalen (in Norrland), Lake Vänern Archipelago and Mount Kinnekulle and Blekinge Archipelago (UNESCO, 2021), situated in a latitudinal gradient across Sweden and representing different bio-climatic conditions were used as study areas (Fig. 1). Complemented with a literature overview focusing on literature that is directly relevant to the study (e.g. communication needs and behaviour of garden owners), an expert group consisting of the managers of the three biosphere reserves, the national coordinator for the Swedish biosphere reserves, experts on IAS at the Swedish Environmental Protection Agency and the Swedish Species Information Centre (including the person responsible for the national risk assessment of invasive alien vascular plant species), were invited to share their knowledge and experiences of IAS in the designated biosphere reserves. The outcomes of the discussions were used to construct an influence diagram (see, Morgan et al., 2001) visualising the most important aspects and their causative relations to focus on in relation to invasive

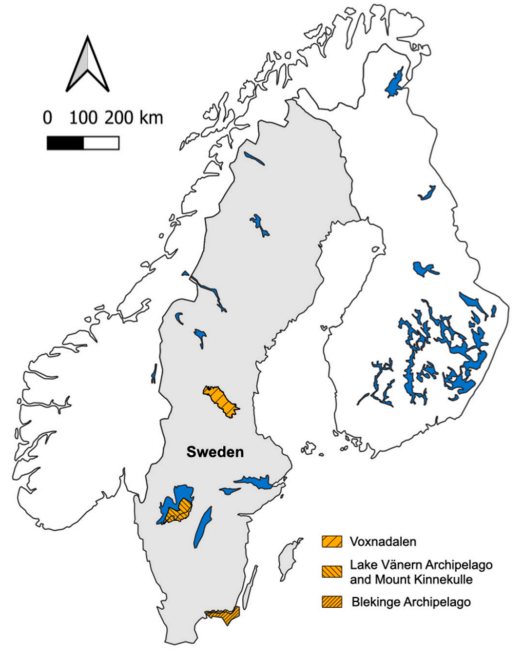

Fig. 1. Location of the study areas Voxnadalen, Lake Vänern Archipelago and Mount Kinnekulle and Blekinge Archipelago, in Sweden. Made with Natural Earth.

garden plant species that threaten the local biodiversity in the study areas (cf. Fischhoff, 2013). Semi-structured interviews with four to five garden owners in each study area were conducted to complement the influence diagrams with aspects that are important to garden owners but were unknown, or not prioritised, by the professional invasive species experts.

2.2. Survey

The influence diagram was used to formulate questions for a survey of domestic garden owners in the three study areas. The interviews helped to focus the survey as well as providing input concerning which species to focus on. The purpose of the interviews was also to make sure that the terminology to be used in the survey was comprehensible to the receivers (see de Bruin and Morgan 2019). Approximately 6000 randomly sampled domestic garden owners (approximately 2000 in each study area) were invited to participate in the survey which used postal invitations to a web-based questionnaire (Fig. S1) using the survey tool Netigate (2021). A cover letter (Fig. S2) informed the respondents of the objectives and the purpose of the study. Participation in the survey was voluntary and none of the questions included were compulsory to answer. All questions in the questionnaire and the information in the cover letter were formulated in Swedish. The survey was open for access from October 22 to December 7 in 2020 and resulted in 990 responses (Text S1).

The questionnaire included 24 questions on IAS, their relation to biodiversity, and climate change. Questions in the questionnaire asked about five plant species for this study, Himalayan balsam, *Impatiens glandulifera* Royle, Garden lupin, *Lupinus polyphyllus* Lindl., Japanese knotweed, *Reynoutria japonica* Houtt., Rugosa rose *Rosa rugosa* Thunb., and Lilac *Syringa vulgaris* L., all of which had been selected from the Swedish risk assessment on IAS, category "Severe Impact" (see Strand et al., 2018). All five species were originally introduced as ornamentals and are common garden species, grown in all the three study areas (Artfakta 2023). Henceforth, the species included in the study will be called "set of species" when referred to as a group. The species in the questionnaire were presented to the respondents in random order.

The present study draws upon seven of the questions included in the questionnaire. These concerned knowledge level, management against IAS, species-identification skills, presence of IAS in the respondents' gardens, experience of biodiversity loss, and expectations of climate change impacts on the invasiveness of invasive species. Four additional questions on socio-demographics targeting age, gender, municipality, and gardening interest were also used in the study. Five hundred and sixty-six responses from respondents having responded to all the questions used for variable construction were analysed.

Arguably, only respondents familiar with the concept of IAS and respondents who have at least one IAS in their garden can be expected to take measures to control IAS. Garden owners with at least one of the species in the set of species were thus selected for use in the subsequent analysis (Q1 and Q3 in Table 1). To know if a certain species is growing in a garden, moreover, requires the skill to identify the species. The self-stated identification skills of the respondents varied greatly depending on the target species. In addition to variation in identification skills between species, geographical variation in identification skills between the three biodiversity reserves were found (Table S1).

2.3. Variable construction

The dichotomous response variable *control* was constructed from the question relating to measures for control of IAS taken in the respondent's garden with the response alternatives yes = 1 and no = 0 (Q4 in Table 1). A Bayesian Additive Regression Tree (BART) model modified to handle classification for dichotomous response variables (Kapelner and Bleich, 2016) was fitted to the data to predict the probability of *control* (cf. Blennow et al., 2020).

Table 1
Questions analysed in the present study.

Number	Question	Response option
Q1	Do you know the meaning of the term 'invasive species'?	Yes No
Q2	Do you know the species: Applied to 5 invasive species[a,b]	Yes No [c]
Q3	Does this species grow in your garden? Applied to 5 invasive species[a,b]	Yes No Do not know
Q4	Have you or anyone else taken measures to control invasive species in your garden?	Yes No
Q5	Have you experienced biodiversity loss in your local environment due to invasive alien species	No, I have definitely not experienced that (-3)- 2 −1 Do not know 1 2 Yes, I have definitely experienced that (3)
Q6	How much do you appreciate the following species? Applied to 5 invasive species[a,b]	Not at all (0) 1 2 3 Much (4) Do not know
Q7	Do you believe climate change leads to changes in invasive alien species?[d]	Definitely not (-3)- 2 −1 Do not know 1 2 Yes, definitely (3)
Socio-demographic variables		
Q8	In what municipality do you live?	A list of 21 municipalities within the three study areas
Q9	How old are you?	<21 years old 21–30 years old 31–40 years old 41–51 years old 51–60 years old >60 years old
Q10	Gender	Woman Man Other or do not want to disclose
Q11	How interested in gardening are you?	Scale from Not interested (0) to Very interested (4)

[a] *Impatiens glandulifera*, *Lupinus polyphyllus*, *Rosa rugosa*, *Reynoutria japonica*, *Syringa vulgaris*. Only the Swedish common names were presented in the survey, see Text S1.
[b] Order of species randomised.
[c] Answer options reformulated from the original survey. For original formulation see Fig. S1.
[d] Question reformulated from the original survey. Here, the strength of belief in the effects of climate change was taken as the inverse of the responses to the question. For original formulation of the question, see Fig. S1.

Six questions asked in the survey were used to construct the 25 variables that were tested as predictors in the model and these were subsequently used to test empirical consequences of the hypotheses H1–H3. The variables *identification Impatiens, identification Reynoutria, identification Rosa, identification Lupinus* and *identification Syringa* were constructed to reflect the self-stated ability to identify each of the five plant species and was based on Q2 (Table 1). The variables *garden presence Impatiens, garden presence Reynoutria, garden presence Rosa, garden presence Lupinus and garden presence Syringa* were constructed to reflect whether each of the species were growing in the respondent's garden and were based on question Q3 (Table 1). The variable *biodiversity loss* was constructed to reflect whether the respondents had experienced biodiversity loss in their surrounding environment due to

IAS and was based on Q5 (Table 1). The variable *appreciation of species* was constructed to reflect the self-stated appreciation of each of the five IAS species in the set of species, and was based on Q6 (Table 1). The variable *climate change impacts* was constructed to reflect how strongly the respondent believed in climate change impacts on the invasiveness of IAS and was constructed from Q7 (Table 1). Two compound variables were constructed. The variable *garden presence* was constructed by counting the number of plants stated to be present in each of the garden owner's garden, and the variable *Study area* was constructed by aggregating the respondents based on municipality of residence in the three study areas included in the study. The variable *Study area* was not included in the BART model but was used for the Bayesian proportion tests.

2.4. Statistical analysis

The most important variables were identified and statistically tested for their importance as covariates following Kapelner and Bleich (2016). Variables not significantly contributing to the model were dropped in a backwards stepwise manner, and only variables with a significant effect were retained in the final model. To test if the difference in proportions (probabilities of success) between groups of respondents was significant, a single-sided Bayesian proportion test was used, applying a uniform prior distribution (Bååth, 2014). All tests were conducted at $\alpha = 0.05$. Descriptive statistics of the responses to the survey questions used in this paper are found in Table S2 in the supplementary material.

The open-source software R Project for Statistical Computing v 3.6.2 was used to analyse the data (R Core Team, 2019). The packages Bayesian first aid (Bååth, 2014) and BART-Machine (Bayesian Additive Regression Trees) v 1.2.6 were used (Kapelner and Bleich, 2016) for all analyses.

3. Results

3.1. Beliefs and values

H1: The strength by which garden owners believe that they have experienced local biodiversity loss due to invasive species correlates positively with measures taken to control invasive species in their gardens (*cf.* Niemiec et al., 2016)

We found that the answer "Yes, definitely" to the question "Have you experienced biodiversity loss in your local environment due to invasive species" (variable *biodiversity loss)* was positively correlated with measures taken to control IAS in the BART model (Fig. S3).

A correlation between the strength of belief in having experienced local biodiversity loss due to IAS and reporting to have taken measures to control IAS was found for all three study areas. Moreover, 21–28% of the respondents in each study area reported being uncertain whether they had experienced biodiversity loss due to IAS (Table S3, test 2–4).

A geographical variation in the proportion of garden owners who had taken measures to control IAS between the study areas was also found, with two thirds of the respondents in the Voxnadalen study area, and one third of the respondents in each of the study areas Lake Vänern Archipelago and Mount Kinnekulle and Blekinge Archipelago (Table S4).

H2: The strength by which garden owners believe in the impact of climate change on the invasiveness of invasive species correlates positively with measures taken to control invasive species in their gardens (cf. Bardsley and Edwards-Jones, 2007)

The respondents' strengths of belief in climate change impacts on the invasiveness of species did not correlate with measures taken to control IAS in their gardens in the BART model. However, when using Bayesian proportion tests for individual study areas, measures taken to control IAS correlated negatively with a determinate belief that climate change does not impact on the invasiveness of alien species for respondents in the Voxnadalen study area, although the test was based on only six responses (Table S3, test 5–8). Moreover, 52% (Voxnadalen), 64% (Lake Vänern Archipelago and Mount Kinnekulle) and 59% (Blekinge Archipelago) of the respondents in each study area, respectively, reported to not knowing if they expect climate change to lead to changes in the invasiveness of alien species.

H3: The strength of appreciation of a specific plant species correlates negatively with measures taken to control invasive plant species (cf. Qvenild et al., 2014; Lindemann-Matthies, 2016)

The following five empirical consequences were tested: the strength of garden owners' appreciation of the invasive alien species (3a) *Impatiens glandulifera*, (3 b) *Lupinus polyphyllus*, (3c) *Reynoutria japonica,* (3 d) *Rosa rugosa* and (3e) *Syringa vulgaris,* correlate negatively with measures taken to control invasive alien plants taken in their own gardens. Lack of appreciation for the species *Lupinus polyphyllus* was positively correlated with measures taken to control IAS in the BART model (Fig. S3), but when tested for individual study areas using the Bayesian proportion test, no correlation was found for the Blekinge Archipelago study area (Table S3, test 9–12).

For respondents stating the presence of *Lupinus polyphyllus* growing in their garden, lack of appreciation for this species was positively correlated with a determinate belief in having experienced local biodiversity loss due to IAS, while weak or strong appreciation of *Lupinus polyphyllus* was negatively correlated with a determinate belief in having experienced biodiversity loss (Table S5, test 1).

Among garden owners reporting to have the species growing in their garden, a lack of appreciation of *Impatiens glandulifera*, *Lupinus polyphyllus* and *Reynoutria japonica,* respectively, correlated positively with measures taken to control IAS, while no correlation was found for garden owners who had *Rosa rugosa* or *Syringa vulgaris* growing in their garden (Table S3, test 13–41). However, a strong appreciation of *Rosa rugosa* and *Syringa vulgaris* both correlated negatively with not having taken measures to control IAS in their garden.

3.2. Socio-demographic factors

Tests of the correlation between measures taken to control IAS and additional socio-demographic factors revealed no correlation with neither age nor gender. However, garden owners reporting very strong interest in gardening were significantly more likely to have taken measures to control IAS (Table S3, test 43–44, S6, test 4).

Self-rated identification skills were significantly higher among respondents holding a strong garden interest. Holding a strong garden interest was positively correlated with both the female gender and the respondent being at least 60 years of age which suggests that the higher identification skills observed among respondents having a strong garden interest may partially be explained by the fact that they were more likely to be over 60 years of age and women. However, the female gender was not correlated with being older than 60 years (except for the species *Impatiens glandulifera*) (Table S6, test 5–9, S7, test 1–10, Table S8, test 1–10, Table S9, test 1–5).

Being very interested in gardening was positively correlated with having a definite belief that one had experienced local biodiversity loss due to IAS (Table S10, test 2).

4. Discussion

A key component for a garden owner's ability to make decisions regarding IAS, whether it comes to planting, eradication, or reporting, is to be able to identify the IAS (Prinbeck 2011; Balding and Williams, 2016; Lindemann-Matthies, 2016; Robinson et al., 2016; Jose et al., 2019). In the present study, the garden owners' invasive plant species

identification skills varied greatly depending on species (Table S1). Only approximately half of the garden owners stated to be able to identify the species *Rosa rugosa* in each of the study areas respectively, and less than half of the garden owners stated to be able to identify *Reynoutria japonica* in the study areas Voxnadalen and Lake Vänern Archipelago and Mount Kinnekulle, while two thirds of the garden owners in the study area Blekinge Archipelago stated that they could identify the species (Table S1). For *Impatiens glandulifera*, approximately half of the garden owners in the study areas Voxnadalen and Lake Vänern Archipelago and Mount Kinnekulle stated that they are able to identify the species while only one fourth of garden owners in the study area Blekinge Archipelago stated that they are able to identify the species. These species represent some of the most common IAS in Sweden (Swedish Environmental Protection Agency, 2022). It has been observed that the general public sometimes lacks the necessary skills to identify IAS in other parts of the world as well (Netherlands: Verbrugge et al., 2013; Portugal: Cordeiro et al., 2020; South Africa: Shackleton and Shackleton, 2016; Colorado, USA: Daab and Flint, 2010).

The fraction of garden owners who had taken measures to control IAS were found to vary geographically with approximately two thirds of the garden owners having taken measures to control IAS in the Voxnadalen study area, one third in Lake Vänern Archipelago and Mount Kinnekulle study area, and one third in the Blekinge Archipelago study area (Table S4). Nevertheless, in all of the study areas, the garden owners' measures taken to control IAS correlated with their beliefs in having experienced local biodiversity loss that they attributed to invasion of alien species. Thus, H1, which states that the strength by which garden owners believe they have experienced biodiversity loss locally due to invasive species correlates positively with measures taken to control invasive species in their gardens, was corroborated.

Climate change and IAS are stressors that can both act independently and also exacerbate each other's impacts on biodiversity loss (Hellmann et al., 2008; Mainka and Howard, 2010), and hence climate change is important to consider in IAS management (Beaury 2020). However, in this study, a large proportion of garden owners in all three study areas reported that they do not know if climate change impacts the invasiveness of species (Table S3, test 5–8). Not only does this demonstrate a widespread lack of knowledge of climate change impacts on the invasiveness of species but it also substantially reduces the number of observations on which to base statistical tests of correlation in the present study. Hence, a negative correlation between a determinate belief that climate change has no impact on the invasiveness of alien species and measures taken to control IAS in the Voxnadalen study area was based on the responses of only a few garden owners (Table S3, test 5–8). Therefore, the test of H2, stating that the strength by which garden owners believe in the impacts of climate change on the invasiveness of invasive species correlates positively with measures taken to control invasive species in their gardens, was inconclusive.

Lack of appreciation for *Lupinus polyphyllus* correlated positively with measures taken to control IAS in the Voxnadalen study area as well as in the Lake Vänern Archipelago and Mount Kinnekulle study area (Table S3, test 10–12). The only species for which the degree of appreciation of the species was uncorrelated with measures taken to control IAS, were *Rosa rugosa* and *Syringa vulgaris*. They were both highly appreciated by garden owners and have characteristics such as large colourful flowers and a pleasant scent that are considered typically desirable by laypersons (Mack and Lonsdale, 2001; Lindemann-Matthies and Bose, 2007). The detrimental effects they can cause may thus be outweighed by their perceived beauty (Lindemann-Matthies, 2016).

The empirical consequences stating that the strength of Swedish garden owners' appreciation of the IAS correlated negatively with their measures taken to control invasive alien plants were corroborated for the species (3a) *Impatiens glandulifera*, (3 b) *Lupinus polyphyllus*, (3c) and *Reynoutria japonica,* while the empirical consequences for the species (3 d) *Rosa rugosa* and (3e) *Syringa vulgaris* were not. Thus, the hypothesis was corroborated but only for the species *Impatiens glandulifera*, *Lupinus polyphyllus* and *Reynoutria japonica*. A positive correlation between a lack of appreciation for *Lupinus polyphyllus* and having experienced local biodiversity loss because of IAS indicates that experience of impact on local biodiversity attributed to IAS can reduce the strength of appreciation for the species, and contribute to enhance the garden owner's propensity to take measures to control the IAS. Indeed, Cordeiro (2020) report that knowing that a plant is invasive can have a larger influence than perceived beauty on willingness to control IAS (Cordeiro, 2020).

4.1. Guidelines for effective communications

The following guidelines were developed based on the communication needs identified for effective communications with garden owners in Sweden.

Garden owners.

- who cannot identify IAS need information on how to identify various IAS morphologically. This communication need is particularly common in relation to the species *Impatiens glandulifera* in the study area Blekinge Archipelago, *Reynoutria japonica* in the study areas Voxnadalen and Lake Vänern Archipelago and Mount Kinnekulle and *Rosa rugosa* in all study areas,
- with no, weak, or uncertain belief in having experienced local biodiversity loss due to invasion of alien species need information that can help them perceive local biodiversity loss due to IAS. Such garden owners were predominately found among garden owners without a strong garden interest and irrespective of study area.
- with no, weak or uncertain belief in climate change impacts on the invasiveness of alien species need information on how climate change can impact on the invasiveness of alien species,
- who appreciate species even if they are invasive, most common for the species *Rosa rugosa* and *Syringa vulgaris*, need information on how invasion of the species can affect biodiversity.

5. Conclusions

The study aimed to identify the communication needs of Swedish garden owners with regards to taking measures to control IAS in their gardens. The study found that communication efforts should focus on enhancing garden owners' identification skills for common IAS and locally adapting communications to meet geographic variations in IAS distribution. Communications that fortify the belief that one has experienced impacts of IAS on the local biodiversity can be expected to increase measures to control IAS among those who have no, or only weak, belief that they have experienced the impacts of IAS on the local biodiversity. Additionally, communication efforts should also provide information on the impacts of climate change on the invasiveness of alien species.

The study found that lack of appreciation for certain IAS species, such as *Impatiens glandulifera*, *Lupinus polyphyllus*, and *Reynoutria japonica*, positively affected measures taken to control IAS in the garden owners' gardens. Lack of appreciation for *Lupinus polyphyllus* was also positively correlated with garden owners' belief in having experienced local biodiversity loss due to IAS, indicating that communication focusing on local biodiversity loss can also enhance measures to control IAS.

The findings from this study suggest that evidence-based guidelines for effective communications can help meet the communication needs of garden owners in different parts of Sweden for controlling IAS in their gardens by giving examples of what to focus the communications on. However, further research is necessary to evaluate the effectiveness of the guidelines for effective communication and ensure successful dissemination to those who can take action to prevent the spread of IAS.

Credit author statement

CP - Conceptualization, Formal analysis, Writing – original draft. AW - Conceptualization, Writing – review & editing. JP - Conceptualization, Writing – review & editing. MA - Writing – review & editing. KB - Conceptualization, Formal analysis, Writing – review & editing, Project administration, Funding acquisition.

Declaration of competing interest

The authors have declared no competing interests.

Data availability

The data can be accessed (registrator@slu.se) by anyone with a legitimate interest in the data, as long as the transfer of data complies with the Swedish and European regulation on data protection.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.117995.

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ORIGINAL PAPER

Horticultural practices of invasive plants: insights into priorities, awareness, and management among garden owners

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Abstract Ornamental horticultural plants in domestic gardens can constitute a substantial dispersal pool of potentially invasive species. Understanding garden owners' preferences when selecting plants, their awareness of dispersal pathways and how they manage their gardens is critical for effective invasive species control. This study used a survey to investigate Swedish garden owners' (n = 743) plant selection priorities, awareness of invasive species dispersal pathways, and management methods across three biosphere reserves in different bio-climatic regions in Sweden. Results show that garden owners prioritise aesthetics, practical characteristics, such as habitat suitability, hardiness, and biodiversity benefits, such as pollinator support, over geographical origin when selecting plants. Management methods perceived as effective, such as hand weeding and digging, were used more frequently than methods such as hot water and salt, which were considered less effective or whose efficiency was uncertain to the respondents. Gardening interest was significantly associated with both ecological knowledge and preference for biodiversity-supporting benefits. Our findings suggest the need for targeted communication strategies that account for regional geographical and gardening variations, plant-specific information, and actual management method effectiveness. These insights can lead to effective stakeholder engagement in invasive species management in domestic gardens.

Keywords Invasive alien species · Domestic gardens · Yards · Plant selection preferences · Dispersal awareness · Management practices

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Introduction

The flora of domestic gardens consists of a majority of horticultural plant species that are alien to their respective regional floras (Loram et al. 2008; Padullés Cubino et al. 2015; Ward and Amatangelo 2018). Ornamental horticultural plants in gardens often constitute a substantial dispersal pool of potentially invasive plants (Haeuser et al. 2018; Hulme et al.

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2018). Given the widespread presence of gardens, their flora exerts considerable propagule pressure on the surrounding landscape (Mayer et al. 2017; Dehnen-Schmutz and Conroy 2018). While this has been documented in a variety of geographical locations such as South Europe (Padullés Cubino et al. 2015), North America (Ward and Amatangelo 2018), Australia (Kendal et al. 2012), and Puerto Rico (Meléndez-Ackerman and Rojas-Sandoval 2021), the Nordic context remains understudied. However, gardens also provide opportunities for early detection, rapid response and management of invasive species (Dehnen-Schmutz & Conroy 2018; Shackleton and Shackleton 2016). A cost-effective strategy in invasive plant management involves preventing the introduction and dispersal of potentially invasive species (Rouget et al. 2016; García-Llorente et al. 2011). Public knowledge and values regarding invasive species depend partly on how they perceive alien species and their impact on biodiversity, economy and human health, and this can significantly influence management outcomes (Verbrugge et al. 2013).

The success of voluntary efforts for invasive species control depends on various factors, including the garden owners' knowledge and attitudes, as well as the introduction pathway of invasive species. Some alien species are cultivated and valued for their aesthetic appeal (Shackleton et al. 2019) or because they are easy to cultivate, displaying rapid growth and resistance to pests (van Kleunen et al. 2018). According to Shackleton and Shackleton (2016) engaging garden owners in the control of invasive species introduced as ornamentals with aesthetic appeal can be challenging. Garden owners' plant choices can further be shaped by social norms (Goddard et al. 2013), the availability of species in nurseries (Cavender-Bares et al. 2020), and practical considerations like suitability for food production (Gulinck et al. 2020; Šiftová 2021). The interaction between personal preferences and availability creates a self-reinforcing pattern in the selection of plants for gardens (Avolio et al. 2018). As a result of this, garden owners typically rely on a selection of ornamental commercially available species, often overlooking their potential ecological impacts, such as invasiveness (Dehnen-Schmutz et al. 2007) and contribution to biotic homogenisation (McKinney 2006). Research by Kendal et al. (2012) found that garden owners select plants based on specific traits that align with their preferences, such as flower size, foliage colour and drought tolerance. Garden owners may decide to plant or keep invasive species, even when they are aware of their ecological harm, because of positive attributes such as aesthetics or cultural significance (Shackleton and Shackleton 2016; Dehnen-Schmutz & Conroy 2018).

To understand these challenges in a Nordic context, it is important to consider Sweden's diverse climate. Stretching from temperate oceanic conditions in the south to subarctic environments in the north, the country encompasses a wide range of growing conditions that strongly shape its vegetation (Sjörs 1956). This climatic gradient is also evident in the length of the vegetation period, which lasts up to approximately 230 days in the south but shortens to approximately 110 days in the north (SMHI 2025a). More than 50% of the Swedish population lives in houses with a garden (Statistics Sweden 2023), with garden sizes in urban areas typically ranging between 540 and 1120 m^2 (Bengtsson and Haller 2025). Swedish garden design during the latter half of the twentieth century was influenced by functionalism, but has become increasingly more individualistic, reflecting the personal tastes and preferences of garden owners (Wilke 2014). A risk assessment of invasive alien species for Sweden[1] indicates that at least 255 plant species may become invasive within the next 50 years (SLU Artdatabanken 2025), highlighting the specific challenges faced in Nordic climates. Additionally, many ornamental species are currently being cultivated at latitudes higher than their natural distributions, where their naturalisation is presently limited by suboptimal climate conditions (Haeuser et al. 2018). With a warming climate, these cultivated species may overcome current climatic constraints and spread more extensively (Bellard et al. 2013; Dullinger et al. 2017; Gallardo et al. 2017). This is particularly relevant as naturalised alien species tend to move toward higher latitudes, primarily due to larger native species pools at lower latitudes (Zhang et al. 2023). To mitigate the dispersal of invasive species, voluntary management and control efforts among gardeners are imperative (Niemiec et al. 2016; Junge et al. 2019).

[1] This national assessment classifies any plant species introduced by humans that have naturalised in Sweden since 1800 as alien (SLU Artdatabanken 2025).

Moreover, a desire to attract pollinators, support wildlife, and promote biodiversity can also influence decision-making in gardening (Goddard et al. 2013; Home et al. 2019). The evolutionary history shared between native plants and local fauna creates ecological relationships that are important for biodiversity conservation (Tallamy 2007). Gardens can serve as important corridors for native plant species (Doody et al. 2010; Staude 2024), yet the potential disconnect between gardeners' appreciation for biodiversity and their knowledge of plant origin may limit such conservation efforts. Alien origin is a criterion for a plant to be considered invasive (IUCN 2025), and this aspect is often emphasised in governmental agency communications with garden owners regarding invasive plants (Swedish Environmental Protection Agency 2025). Alongside origin, other factors such as species-specific traits, cultivation history, propagule pressure, and climate matching between source and recipient regions also contribute to predicting invasion risk (van Kleunen et al. 2018). However, garden owners may regard origin as relatively unimportant compared to functional or aesthetic traits (Qvenild et al. 2014). There have been reports from Africa, continental Europe and the USA that laypeople, in general, are unable to distinguish native species from alien ones (McKinney 2006; Lindemann-Matthies 2016; Shackleton and Shackleton 2016; Seboko et al. 2024).

Effective control of invasive species requires knowledge of appropriate management techniques (Niemiec et al. 2016) and social acceptance of control methods, particularly when they involve controversial approaches such as herbicide use and lethal removal (Sharp et al. 2011; Olszańska et al. 2016), while preventing further dispersal necessitates safe disposal methods (Krajšek et al. 2020). Selecting the most suitable control measures for a specific situation requires an understanding of the invasive plant's dispersal pathways. To the best of our knowledge, no study has so far investigated which methods domestic garden owners use in their control of invasive plant species. Moreover, knowledge about garden owners' plant preferences, knowledge of dispersal pathways and which control methods garden owners perceive as effective not only informs about the perceived effectiveness of management methods but also provides valuable insights for developing more targeted communications and support for invasive plant management in private gardens across a wider geographical context.

Against this review, we hypothesise that:

Hypothesis 1a Garden owners prioritise cultivation qualities over geographical origin

Hypothesis 1b Garden owners prioritise biodiversity-supporting abilities over geographical origin

Hypothesis 2 Garden owners with personal experience of invasive species in their gardens have a higher awareness of dispersal pathways than those without such experience

Hypothesis 3 The management methods used by garden owners to manage invasive plants correlate positively with the perceived effectiveness of the used management methods

Method

Data

Preparatory work before conducting a survey included a scoping literature review, influence diagrams and explorative, semi-structured interviews with garden owners (n = 14) from the three biosphere reserves (Palmér et al. 2023). This approach aligns with Persson et al. (2018), integrating local knowledge into scientific research, which emphasises the importance of exploratory engagement with stakeholders to understand local contexts and practices, in this case, garden owners, to identify relevant topics before formal data collection (the main survey). The preparatory work facilitated the integration of practical experience from gardeners with theoretical knowledge from domain experts by recognising potential knowledge gaps between these different perspectives.

A survey was distributed to approximately 6000 randomly selected domestic gardeners, specifically domestic garden owners, in the three biosphere reserves located in different bio-climatic regions of Sweden: Voxnadalen, Lake Vänern Archipelago and Mount Kinnekulle, and Blekinge Archipelago (UNESCO 2025) (Fig. 1). These biosphere reserves encompass areas of high biodiversity values with mixed land uses, and the surveyed gardens were situated within the buffer and transition zones rather than within the strictly protected areas. The postal invitations included a link to a web-based questionnaire hosted by Netigate (2025). The respondents were

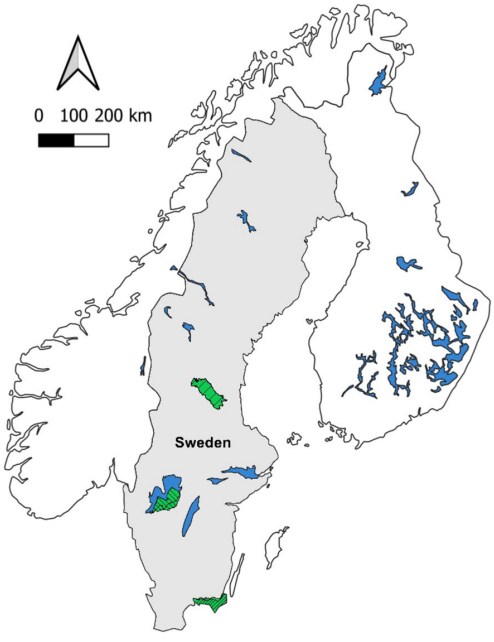

Fig. 1 Location of included study areas in Sweden. Voxnadalen (the northernmost), Lake Vänern Archipelago and Mount Kinnekulle (central) and Blekinge Archipelago (the southernmost). Adapted from Palmér et al. (2023). Made with Natural Earth

informed of the objectives of the study, that participation was entirely voluntary, and that no questions were compulsory to answer, in a postal cover letter. The survey as well as the cover letter were formulated in Swedish. The survey was deployed on October 22 and remained open until December 7 in 2020 and generated 990 responses.

The subsequent survey comprised 24 questions focusing on invasive species, their effect on biodiversity, and how they are expected to be impacted by climate change. All species included in this study are assessed to have a severe impact according to a national risk assessment of invasive species in Sweden and are among the most common invasive plant species in the country (Strand et al. 2018; SLU Artdatabanken 2025). Six invasive plant species were used in the questionnaire: butterfly bush (*Buddleja davidii* Franch.), Himalayan balsam (*Impatiens glandulifera* Royle), garden lupin (*Lupinus polyphyllus* Lindl.), Japanese knotweed (*Reynoutria japonica* Houtt.), rugosa rose (*Rosa rugosa* Thunb.), and lilac *(Syringa vulgaris* L.). However, *Buddleja davidii* was omitted from the present study due to inadequate cold tolerance in the northernmost study area, making it hard to compare between study areas. The order of the species was randomised when presented in the questionnaire. The complete questionnaire is provided in Palmér et al. (2023).

This study analysed four questions from the questionnaire, each containing multiple sub-questions, with the 32 sub-questions treated as individual variables in the analysis. These concerned knowledge level of plant dispersal pathways, management practices, garden owners' perceived effectiveness of management practices, and preferred qualities when choosing plants for gardens. In addition, the variables municipality and gardening interest were included in the analysis. Most respondents (95%) reported knowing what invasive means at the beginning of the survey. After the question concerning the definition in the survey, a definition was given so that everyone who answered the subsequent questions was aware of the definition. Only responses from garden owners with at least one invasive plant species growing in their garden were included in the present study (n = 743). For the test of the hypothesis concerning management methods, making use of responses to Q3 and Q4 in Table 1, only respondents who had taken measures to control invasive species in their gardens were included (n = 328).

Statistical analysis

To test the hypotheses that garden owners prioritise cultivation qualities and biodiversity supporting abilities over geographical origin, a Friedman test was used to assess differences in the median ranks across sub-questions concerning plant preference in Q1 (Table 1). Following a significant Friedman test result, pairwise comparisons were performed using the Conover post hoc test with adjustments for multiple comparisons according to Bonferroni. Kendall's *W* was calculated as the effect size measure.

To test the hypothesis that garden owners with personal experience of invasive species have higher awareness of dispersal pathways, knowledge of the primary dispersal pathway (Q2) was categorised for each of the included species (Online resource Text 1) and analysed using a two-sided test of proportions to

Table 1 Questions analysed in the present study, with abbreviations used in the paper

Number	Question	Response option
Q1	What is important to you when choosing plants for your garden? - That the plant possesses the right traits for the growing site (variable *habitat suitability*) - That the plant is hardy (variable *hardiness*) - Availability in nurseries (variable *availability in nurseries*) - The appearance of the plant (variable *plant aesthetics*) - That the plant produces food (variable *food production*) - That the plant spreads in the garden (variable *spreading*) - That the plant does not spread in the garden (variable *non-spreading*) - That the plant is good for pollinators (e.g. bees, bumble bees and butterflies) (variable *pollinator support*) - That the plant is beneficial for biodiversity (variable *biodiversity beneficial*) - That the plant is alien (variable *alien origin*) - That the plant is Swedish (variable *Swedish origin*)	Not at all important (0) 1 2 3 Very important (4)
Q2	Do you know how the following plants are primarily dispersed? - Himalayan balsam, *Impatiens glandulifera* - Garden lupin, *Lupinus polyphyllus* - Japanese knotweed, *Reynoutria japonica* - Rugosa rose, *Rosa rugosa* - Lilac, *Syringa vulgaris*	Road transport Translocation of soil Birds Wind Water Root suckers Other Do not know
Q3	Have you or anyone else used the following invasive species control measures in your garden? - Digging - Burning - Hot water - Hand weeding - Cutting - Salting - Covering - Chemical substances	Yes, always Often Rarely No, never Do not know
Q4	According to you, are the following invasive species control measures effective? - Digging - Burning - Hot water - Hand weeding - Cutting - Salting - Covering - Chemical substances	Yes, always Often Rarely No, never Do not know
Q5	In what municipality do you live?	A list of 21 municipalities subsequently aggregated into three study areas, Voxnadalen, Lake Vänern Archipelago and Mount Kinnekulle and Blekinge Archipelago
Q6	How interested in gardening are you?	Not interested (0) 1 2 3 Very interested (4)

determine group differences. Cramér's V was calculated as the effect size measure.

To test the hypothesis that management methods correlate positively with perceived effectiveness, Spearman's rank correlation analysis was conducted to evaluate the relationship between reported use and the effectiveness of each management method (Q3, Q4), with "I do not know" responses excluded prior to analysis, as they cannot be meaningfully ordered within the ordinal scale for rank correlation. The Spearman's rank correlation coefficient (ρ) served as the effect size measure.

Variables for study area (based on municipality) (Q5) and gardening interest (Q6) were analysed using the Kruskal Wallis test for Q1, Q3 and Q4, followed by Dunn's post hoc test with Bonferroni correction when significant. Effect sizes were assessed using eta-square (η^2). For Q2, Pearson's χ^2 was used to examine associations between study area, gardening interest and correctly identified dispersal pathways, followed by a pairwise test of proportions with continuity correction when the overall test was significant. Effect sizes were assessed using Cramér's V. To check for co-variation between the ordinal variables study area and gardening interest, Goodman–Kruskal γ and Somers' D were used.

The open-source software R Project for Statistical Computing v 4.3.2 was used to analyse the data (R Core Team 2023). All analyses were performed using the car (Fox and Weisberg 2019), DescTools (Signorell 2024), dunn.test (Dinno 2024), stats (R Core Team 2023), PMCMRplus (Pohlert 2024), rstatix (Kassambara 2023) and vcd (Meyer et al. 2024) packages in R. Visualisations, including graphs, were created with the ggplot2 (Wickham 2016) and dplyr (Wickham 2023) packages. For all statistical tests, the significance level (α) was set at 0.05.

Results

Hypothesis 1a *Garden owners prioritise cultivation qualities over geographical origin.*

A Friedman test revealed a statistically significant difference in the ranking across factors ($\chi^2(8) = 2483$, $p < 2.2e{-}16$, Kendall's $W = 0.51$), indicating that respondents rated certain factors as consistently more important than others when choosing plants for their gardens (Q1) (Fig. 2). The variables *plant aesthetics*, *habitat suitability*, *hardiness*, *availability in nurseries* and *non-spreading*, showed similarly high median rankings. Both origin-related factors were ranked significantly lower. *Swedish origin* had a median ranking of 2, while *alien origin* had a median ranking of 0 (not important at all). In the pairwise comparisons (Conover post hoc test), all four factors ranked least important were significantly different from each other, and all other included variables (Fig. 2, Online resource Table 1).

Habitat suitability of plants was rated as more important by respondents with a strong interest in gardening than those with lower interest, indicating a significant association between gardening interest

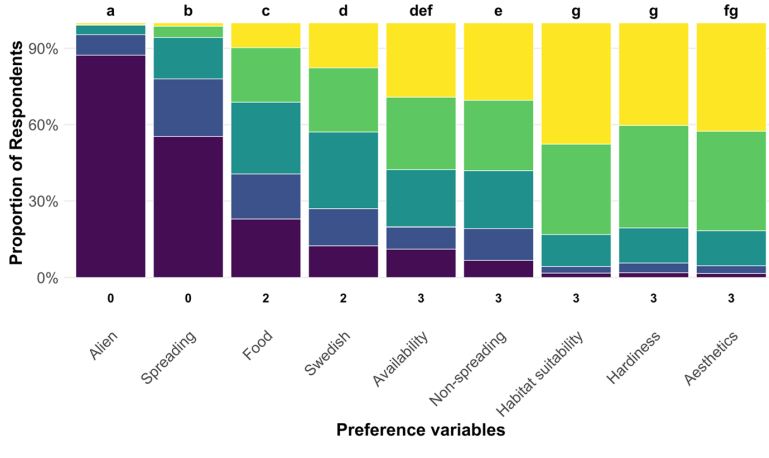

Fig. 2 Importance ratings for how Swedish garden owners rate cultivation qualities and geographical origin, Q1 in Table 1. Letters = statistical groups. Numbers under the bars indicate median rank (sorted by median importance). 4 very important (yellow), 3 (green), 2 (turquoise), 1 (blue), 0 not important (dark blue)

and the value placed on *habitat suitability*. No significant co-variation was found between the study areas and gardening interest (Goodman–Kruskal $\gamma = 0.080$, Somers' $D = 0.052$). In the northernmost study area (Voxnadalen), respondents placed significantly higher importance on plant *hardiness* compared to respondents in the southern Blekinge archipelago. Voxnadalen respondents also showed a stronger preference for native *Swedish* plants than respondents from the other study areas. Both Voxnadalen respondents and respondents with a strong gardening interest valued *food production* plants highly (Online resource Table 2).

Hypothesis 1b *Garden owners prioritise biodiversity-supporting abilities over geographical origin.*

A Friedman test revealed a statistically significant difference in the rankings across biodiversity-supporting abilities ($\chi^2(3) = 1231$, $p < 2.2e\text{-}16$, Kendall's $W = 0.675$). A post hoc Conover test showed that all included variables were rated significantly differently (Online resource Table 3). *Pollinator support* was ranked as the most important variable, followed by *biodiversity beneficial*, *Swedish* origin and *alien* origin (Fig. 3).

There was a general tendency in all three study areas to find *pollinator support* important, but respondents from Blekinge archipelago were significantly more likely to find pollinators important than respondents from Lake Vänern Archipelago and Mount Kinnekulle (Online resource Table 4). Respondents with strong gardening interest were more likely to see both *biodiversity beneficial* and *pollinator support* as important than respondents with less strong interest.

Hypothesis 2 *Garden owners with personal experience of invasive species in their gardens have a higher awareness of dispersal pathways than those without such experience.*

Respondents who had *Impatiens glandulifera*, *Reynoutria japonica, Rosa rugosa* or *Syringa vulgaris* in their gardens were significantly more likely to know how these species are dispersed than those who did not (Online resource Table 5). The awareness of dispersal characteristics was positively correlated with gardening interest (Online resource Table 6). Respondents who were very interested in gardening consistently reported better knowledge of dispersal for all the included species. A geographical difference was found for *Reynoutria japonica* where garden owners in Blekinge archipelago reported a higher knowledge level than garden owners in Voxnadalen and Lake Vänern Archipelago and Mount Kinnekulle. An opposite pattern was found for *Impatiens glandulifera* where respondents in Blekinge reported a lower knowledge level than garden owners in Voxnadalen and Lake Vänern Archipelago and Mount Kinnekulle.

Hypothesis 3 *The management methods used by garden owners to manage invasive plants correlate*

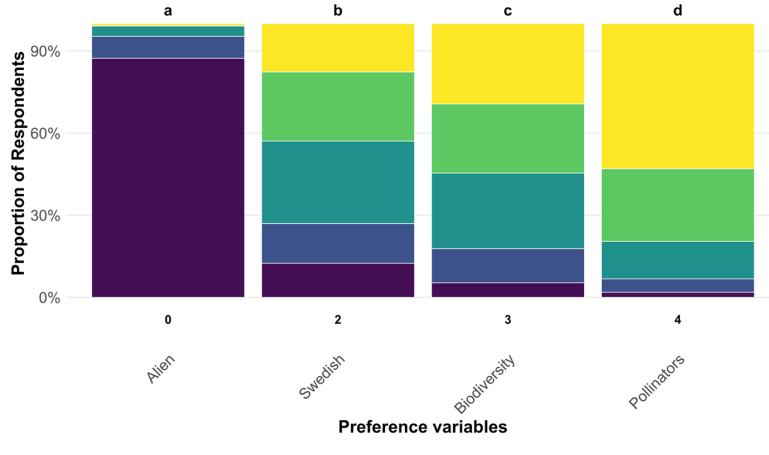

Fig. 3 Importance ratings of biodiversity-supporting abilities and geographical origin by Swedish garden owners, Q1 in Table 1. Letters = statistical groups ($p < 0.05$). Numbers under the bars indicate median rank (sorted by median importance). 4 very important (yellow), 3 (green), 2 (turquoise), 1 (blue), 0 not important (dark blue)

positively with the perceived effectiveness of the used management methods.

Results of the Spearman rank correlation tests showed that each of the management actions was significantly positively correlated with the perceived effectiveness of the management methods ($p < 0.001$ for all management actions) (Online resource Table 7). Sample sizes for these correlations ranged from 82 (management method *Water*) to 270 (management method *By hand*) (Online resource Table 8).

For management actions, the methods *hand weeding*, *cutting* and *digging* were frequently used (median response: "often"), and *hand weeding* and *digging* were often perceived as effective. However, *burning*, *chemical substances*, *salt* and *hot water* were not frequently used, and *salt* and *hot water* were rarely considered effective (Fig. 4).

Respondents in Voxnadalen were significantly more likely to report never having used *chemical substances* than those in Lake Vänern Archipelago and Mount Kinnekulle, or in Blekinge Archipelago. They were also more likely to perceive these substances as not effective (Online resource Table 9).

Discussion

In this study, we surveyed garden owners across three biosphere reserves (Voxnadalen, Lake Vänern Archipelago and Mount Kinnekulle, and Blekinge Archipelago) in different bioclimatic conditions in Sweden (Fig. 1). We hypothesised that garden owners would prioritise practical plant characteristics and biodiversity benefits over geographical origin, that direct experience with invasive species would increase awareness of dispersal pathways and that management methods use would correlate with perceived effectiveness.

Hypothesis 1a *Garden owners prioritise cultivation qualities over geographical origin.*

Most factors concerning practical plant characteristics, such as plant aesthetics, hardiness, and habitat suitability, were ranked highly, suggesting that garden owners find several factors important when selecting plants for their gardens. Origin was constantly perceived as less important than other included variables. The relatively low rankings of Swedish origin, especially in comparison to practical attributes like hardiness and plant aesthetics, suggest that gardeners are less likely to consider plant origin as a key factor in their decisions. However, while native origin was not considered very important, alien origin was consistently ranked as unimportant, suggesting that garden owners neither specifically select nor avoid plants based on their origin. Based on these results, the hypothesis, stating that garden owners prioritise practical plant characteristics over the values associated with plant origin, was corroborated.

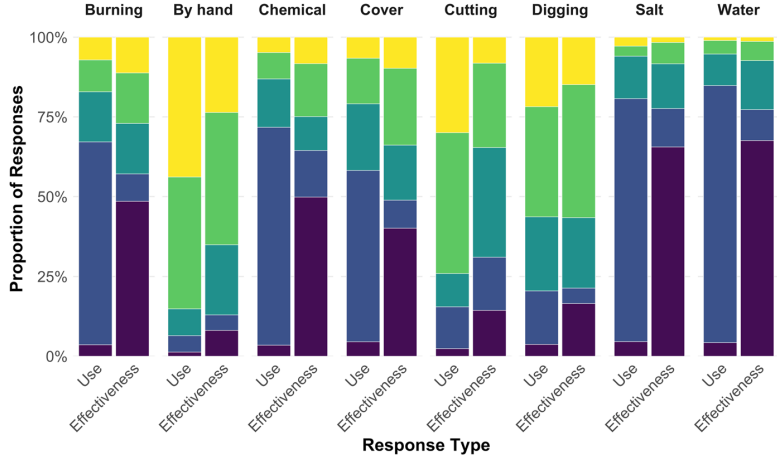

Fig. 4 Proportions of Swedish garden owner responses to management method used and perceived effectiveness of these methods. Always (yellow), often (green), rarely (turquoise), never (blue), do not know (dark blue)

That Swedish garden owners in this study valued plant aesthetics highly aligns with Shackleton and Shackleton (2016), who found that gardeners in South Africa appreciated the aesthetic qualities of invasive plants even while recognising the potentially problematic ecological impacts. The practical cultivation considerations correspond with the findings from Kendal et al. (2012), who noted that gardeners in Australia, in addition to aesthetic appearance, also prioritise practical considerations such as hardiness and habitat suitability in their plant selection process. The findings also align with Qvenild et al. (2014), who observed that gardeners in Norway frequently do not consider whether plants are native or alien when gardening, and Šiftová (2021), who observed that Czech gardeners also ranked using native plants as one of their lowest priorities in garden maintenance. In Mexico, the proportion of native species in domestic gardens has been seen to vary along the urban–rural gradient (Poot-Pool et al. 2015). However, these studies represent a limited geographical scope and may not capture the full range of gardening motivations across different cultural and socioeconomic contexts globally.

Results also align with the findings that spreading plants are most often seen as not preferred (Saltszman et al. 2016). Furthermore, the Swedish garden owners' general disregard of growing plants for food is consistent with Clayton (2007), where food production was ranked as less important than other gardening activities among gardeners in Ohio, USA. It is, however, in contrast with Šiftová (2021), who found food production to be the most common gardening activity in Czechia. Research on domestic gardens from Cuba (Wezel and Bender 2003) and Mexico (Blanckaert et al. 2004) suggests that food security can be an important motivation, highlighting the need for diverse geographical perspectives in understanding gardeners and their relationships to their gardens. These divergent findings concerning food production underscore that gardening practices and preferences are not necessarily universal but can reflect cultural and geographical contexts, economic conditions and gardening traditions.

Hypothesis 1b *Garden owners prioritise biodiversity-supporting abilities over geographical origin.*

Pollinator support and biodiversity were ranked as more important than origin, which was ranked as unimportant. Since origin was consistently ranked as of lower importance, the hypothesis was corroborated.

These findings align with McKinney (2006), who found that many garden owners are positive towards species diversity, although they do not possess knowledge of the species' geographical origin. This disconnect is important to acknowledge, as plant origin may affect local and regional flora conservation and biodiversity support, particularly given the role of gardens in native plant dispersal and conservation (Doody et al. 2010; Staude 2024).

Geographical differences and gardening interest

Garden owners in the northern study area Voxnadalen found plant hardiness and Swedish origin more important than other participants. This could be a reflection of the region's climatic challenges, with a mean annual temperature that is 3–4° C lower than for the southernmost study area (Blekinge archipelago) (SMHI 2025b). The preference may be because native local plant material is adapted to harsher climates and the limited availability of cold-tolerant plant material. Local environmental variables, including regional climate conditions, have previously been shown to influence plant selection preferences and landscape management decisions (Avolio et al. 2015; Larson et al. 2016). The prevalence of *Lupinus polyphyllus* in Voxnadalen may also have heightened local awareness of invasive alien species. This aligns with findings from Palmér et al. (2023), showing that garden owners in this region were more proactive in managing invasive plants.

Garden owners from this northernmost study area, Voxnadalen, and those with a strong interest in gardening valued food-producing plants more highly. This tendency may reflect regional differences in gardening traditions, with rural or semi-rural areas, such as Voxnadalen, being more prone toward self-sufficiency and food cultivation.

Beyond these geographical patterns, gardening interest significantly influences how garden owners valued habitat suitability, pollinator and biodiversity support. The association between a strong gardening interest and greater horticultural knowledge and practical experience has also been observed in Great

Britain (Loram et al. 2011). Additionally, gardening engagement has been found to correlate with increased awareness of and greater motivation to support local biodiversity (Goddard et al. 2013).

Understanding these variations in gardening priorities is important for developing communication strategies that align with different gardeners' values and motivations. Given that co-evolutionary relationships between local flora and fauna play an important role in biodiversity conservation (Tallamy 2007), there appears to be a need for more effective communication about the ecological benefits of native plants. However, strategies that focus on communicating plant origin alone may not be effective in motivating garden owners to manage invasive species. While our findings suggest that garden owners do not prioritise plant origin in their selection decision, it is important to acknowledge that the relationship between gardener preferences and invasive species management is more nuanced than simply promoting native plants. The horticultural industry plays a crucial role in determining which plants are available to gardeners, and in many regions, the majority of plants sold are alien species, with limited native options available in the trade (van Kleunen et al. 2018). Only a minority of alien species become invasive, and many alien species provide various benefits, though these positive contributions are frequently overlooked in invasiveness risk assessments (Vimercati et al. 2020). From an invasive species management perspective, the priority should be on avoiding the cultivation of plants with invasive traits rather than avoiding alien species altogether. Overall, the results underscore the complexity of garden owners' decision-making, where practical cultivation concerns and biodiversity-supporting factors often take precedence over plant origin.

Hypothesis 2 *Garden owners with personal experience of invasive species in their gardens have a higher awareness of dispersal pathways than those without such experience*

A significant association between presence and awareness of dispersal pathways was found for the four species *Impatiens glandulifera, Reynoutria japonica*, *Rosa rugosa* and *Syringa vulgaris*. Since the association was not found for the entire group of species, the hypothesis that garden owners with personal experience of invasive species in their gardens have a higher awareness of dispersal pathways than those without such experience, was partially corroborated.

In addition to seed dispersal, three of the species where positive associations were found, *Reynoutria japonica*, *Rosa rugosa* and *Syringa vulgaris*, all have distinct root suckering dispersal. That garden owners with these species in their garden had significantly better knowledge level of dispersal is likely due to that the local impact of root suckering is relatively easy to detect. The dispersal source is often apparent even to individuals without specialised expertise in botany. In clonal dispersal, the offspring are genetically identical to the parent plant (Oborny and Bartha 1995), making identification straightforward. In contrast, seed dispersal tends to occur over longer distances (Traveset et al. 2014), and the source of dispersal may be less apparent. Seed dispersal is furthermore typically sexual, resulting in offspring that may exhibit some degree of morphological variation from the parent plant. It should be noted that *Lupinus polyphyllus* is a very common invasive species in Sweden (Tyler et al. 2015), and the lack of significant association between this species and personal experience in one's own garden may be because it is widely recognised by a large proportion of the population (Palmér et al. 2023).

This variation in garden owners' knowledge of the dispersal pathways among species supports Verbrugge et al. (2013), who found that risk communication on invasive species benefits from regional and species-specific information. Similarly, Persson et al. (2018) suggest that effective sustainability solutions can be enhanced when they draw on both scientific evidence and local knowledge, as site-specific observations can reveal important patterns not captured by broader scientific approaches alone. It should be noted that species identification skills varied among respondents, particularly for *Impatiens glandulifera*, *Reynoutria japonica* and *Rosa rugosa*. Poor plant identification may contribute to knowledge gaps about dispersal pathways. Prinbeck et al. (2011) identified that for gardeners, specific and localised information about invasive species and their prevention was critical for overcoming barriers to behavioural change, emphasising the need for clear, targeted guidance rather than general information.

Garden owners with a greater interest in gardening showed higher levels of knowledge of dispersal pathways. This aligns with previous studies indicating that gardening experience and interest are associated with greater ecological knowledge and engagement (Goddard et al. 2013). These findings suggest that targeting communication efforts toward less engaged garden owners might help bridge knowledge gaps in invasive species management.

Hypothesis 3 *The management methods used by garden owners to manage invasive plants correlate positively with the perceived effectiveness of the used management methods.*

When it comes to management methods, a significant positive correlation was observed across all management methods. As positive correlations for the use and perceived effectiveness were found for all included methods, the hypothesis was corroborated.

Methods that were most frequently used, such as hand weeding and digging, were also those most commonly seen as effective. In contrast, methods such as burning, the use of chemicals, salt, and hot water were used less frequently and respondents more often indicated they did not find them effective or did not know how effective these methods were (Fig. 4).

The acceptance of manual methods such as digging while being sceptical against chemical use is consistent with Olszańska et al. (2016), who found the same pattern among representatives from the general public and nature conservationists in Poland. However, the low use of chemical substances is in contrast with Varga-Szilay et al. (2024), where more than 60% of Hungarian gardeners reported using pesticides of some form, in their gardens.

The results from our study, moreover, suggest a potential gap between the perceived and actual effectiveness of certain management actions, such as covering the ground and the use of hot water. Covering the ground can be effective when properly implemented, though success rates vary depending on application methods, species and duration (Martin et al. 2020; Dusz et al. 2021), and the use of hot water can achieve very high control rates for some invasive species when applied correctly (Oliver et al. 2020). These methods may be less understood or less accessible to garden owners, or they may be seen as more labour-intensive, expensive, or environmentally harmful.

This finding emphasises the need for communications on invasive species management that take into account which methods garden owners perceive as being effective. Methods that are perceived as effective (e.g., hand weeding and digging) may be even more widely adopted or even more effective if garden owners are provided with additional training or resources on how to improve their efficacy, whereas methods perceived as less effective may require re-evaluation or adjustment in practice. For instance, ground covering effectiveness could be enhanced by providing guidance on appropriate materials, proper application methods and the duration of time required for successful outcomes.

We suggest that a deeper understanding of how personal experience affects garden owners' decisions is essential to designing effective communication and interventions. A targeted approach will help bridge knowledge gaps and empower garden owners to make informed decisions about planting, cultivation, and management of invasive species.

Conclusion

The findings from this study reveal that plant aesthetics, practical plant characteristics and biodiversity-supporting benefits were consistently ranked higher than plant origin. This suggests a possible disconnect in communication between expert recommendations, emphasising origin, and the garden owners' priorities and practices. However, the relationship between plant origin awareness and invasion management is complex. Effective invasion prevention requires both addressing the limited availability of native plants in the horticultural trade and focusing management efforts on species with demonstrated invasion potential rather than all alien species. Regional differences in gardening priorities, influenced by climatic conditions and local invasive species presence, further emphasise the need for targeted communications.

Awareness of invasive species dispersal pathways was high for species with obvious and localised dispersal methods, such as root suckering. This points to the importance of information about less apparent dispersal pathways to enhance public understanding.

Garden owners tended to use and perceive as effective the manual management methods that were most accessible and familiar, such as hand weeding and digging, while more labour-intensive or costly methods were less favoured. This reflects a need to balance practicality and ecological effectiveness when advising on invasive species management.

These findings highlight the complexity of garden owners' decision-making processes and the importance of communication that meets the needs of the garden owners' priorities and perceptions. By bridging the gap between expert knowledge and used gardening practices, efforts to promote sustainable gardening and invasive species management can become more impactful and widely adopted.

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Data availability Data will be made available on reasonable request.

Declarations

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This thesis develops evidence-based guidelines for communicating about invasive alien species to domestic garden owners through exploration of Swedish garden flora and garden owners' knowledge and experiences. Field inventories reveal high species diversity and compositional uniqueness in domestic gardens. Results from a survey emphasise the need for species-specific information and regionally adapted communication strategies that address garden owners' values, knowledge gaps, and practical management approaches.

Cecilia Palmér received her postgraduate education in Biology at the Department of Landscape Architecture, Planning and Management and her undergraduate degree in Landscape Planning at the Swedish University of Agricultural Sciences, Alnarp.

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SLU generates knowledge for the sustainable use of biological natural resources. Research, education, extension, as well as environmental monitoring and assessment are used to achieve this goal.

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