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How do gardeners define ‘invasive’? Implications for invasion science and environmental policy instruments on invasive species

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ABSTRACT

Ornamental horticulture is a main introduction pathway for invasive species globally and gardens are a source of potentially invasive species. Gardeners are therefore important actors (i.e. stakeholders) for invasion science and environmental policies on invasive species. Yet, to the authors' knowledge, no previous study has asked gardeners directly how they define ‘invasive’, and compared this to definitions used within invasion science and environmental policies. For this reason, gardeners were asked to define an ‘invasive’ plant. A deductive approach to thematic analysis of the responses, using key concepts in invasion science and relevant environmental policies, explored the connections between the concepts. This demonstrated the nuanced perceptions and definitions of ‘invasive’ amongst gardeners in Britain, including similarities with how ‘invasive’ is defined especially with the two key concepts of spread and impact. Clear differences were also found; importantly most gardeners only considered the term ‘invasive’ within their gardens (as opposed to the wild). The study also finds that there is better mutual understanding of the term ‘invasive’ between invasion scientists and gardeners than with those involved in environmental policies. Understanding how gardeners define ‘invasive’ has important implications for engaging them with invasion science by exploring the factors determining behaviours in terms of invasive species. This is particularly important in going beyond raising awareness and towards influencing behavioural change more effectively. This study is also relevant to making environmental policies, and especially in their implementation by better knowing how gardeners perceive the issue of invasive species.

1. Introduction

Invasive species are regarded as one of the five direct drivers of change in nature (IPBES, 2019). A main introduction pathway or source of invasive species globally is ornamental horticulture (e.g. Arianoutsou et al., 2021; Drew et al., 2010; Hulme et al., 2017; van Kleunen et al., 2018). Gardeners are therefore essential actors (i.e. stakeholders) and constituents of the ‘publics’ (Davis and Thompson, 2000; Head, 2017) for invasion science and relevant environmental policies, requiring engagement to encourage behavioural change (Doody et al., 2014; Goddard et al., 2010; Loram et al., 2011). There is both inconsistent and inaccurate use of terminology within invasion science (Falk-Petersen

et al., 2006; Pyšek et al., 2004), despite efforts to reach consensus (Blackburn et al., 2011; Colautti and MacIsaac, 2004; Essl et al., 2018; Falk-Petersen et al., 2006; Richardson et al., 2000), and between invasion science and environmental policies. This could limit science communication and engagement efforts with gardeners. It is also important for invasion scientists and those involved in environmental policies to realise that understanding of the term ‘invasive’ can be temporally and spatially specific (Head, 2017; Head and Muir, 2004).

This is explored here by looking at how gardeners in Britain define ‘invasive’ and comparing this with how the term is defined by invasion scientists and in environmental policies. The present study has implications for how invasion scientists communicate and engage with

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gardeners, and for the implementation of domestic and international environmental policy instruments on invasive species.

1.1. Defining ‘invasive’

Here six key concepts, which are common in invasion science and environmental policies in defining ‘invasive’, are considered while linking them with gardeners’ perspectives.

1.1.1. ‘Nativeness’

The focus of this study is not ‘nativeness’ itself (Head, 2017; Head and Muir, 2004; Warren, 2007), but the concept needs to be explored briefly. Both invasion science and environmental policies mostly consider an invasive species to be *a priori* non-native (i.e. introduced or alien), meaning that they have been introduced by humans (intentionally or unintentionally) beyond their native range (Macpherson et al., 1996; Rejmánek, 1995; Rejmánek, 2000; Stace and Crawley, 2015). Limitations to the concept of nativeness (Davis et al., 2011; Fall, 2021) include it being spatially and temporally dynamic (Head, 2017; Qvenild et al., 2014) and what is categorised as being ‘introduced by humans’ (Warren, 2007). Furthermore, this understanding of nativeness specifically referencing origin is relatively recent, with the term having had a closer meaning to ‘wild’ until the late 1700s (Fall, 2021; Thompson, 2014). Kendle and Rose (2000) discussed the spatial and temporal aspects of nativeness; important here is that it can be subjective. Gardeners might define native as a “*species that naturally grows wild in a particular area*” (Brickell, 2008: 1122). This does not necessarily match how ‘native’ is defined within invasion science and environmental policies, in which it is applied across a study area - often linked to geopolitical boundaries (Head and Muir, 2004) - as a whole (Pyšek et al., 2004; Richardson et al., 2000). This rarely matches ecological or biogeographical ‘belonging’ (Head and Muir, 2004) and the distinction of the nativeness of a plant might differ between the garden and the wild (Gill et al., 2010; Head et al., 2015), or not be important for gardeners (Qvenild et al., 2014). For example, Hoyle (2021) found evidence of an aesthetic preference amongst garden visitors for non-native planting in gardens (Hulme et al., 2017) which were perceived as more interesting than native species, although preferences can differ widely including those based on nativeness (Kendal et al., 2012) and can reflect attitudes towards nature (Kendal et al., 2012; Zagorski et al., 2004) and current gardening fashions (e.g. Fowler, 2022).

1.1.2. Escape

For an ornamental to be invasive - as defined within invasion science and environmental policies - species must initially succeed in escaping cultivation (a garden) into the wild (*sensu* Blackburn et al., 2011). This can be explained, for example by i) inherent attributes, i.e. traits (Milbau and Stout, 2008; Rojas-Sandoval and Ackerman, 2021; Stace and Crawley, 2015); and ii) propagule pressure (Cassey et al., 2018; Guo et al., 2019; Lenzner et al., 2021; Rojas-Sandoval and Ackerman, 2021) as a consequence of gardening (Dehnen-Schmutz et al., 2007; Hulme et al., 2017; Lockwood et al., 2009; van Kleunen et al., 2020). Enders et al. (2020) describe both as ‘concept clusters’ which are important in invasion science. They are also important for how gardeners define ‘invasive’ because they are integral to explaining how ornamentals escape gardens. An important point not often considered within invasion science, despite its practical importance, is that gardeners can choose plants with attributes such as rapid growth or spreading (Rojas-Sandoval and Ackerman, 2021; van Kleunen et al., 2018) because of - rather than despite - such ‘invasive characteristics’ as they often require less care (Doody et al., 2014; Hitchings, 2003, 2007; Saltzman and Sjöholm, 2017; Wallington, 2020).

1.1.3. Spread

Although there is no consensus, many in invasion science (e.g. Blackburn et al., 2011; Richardson et al., 2000; Simberloff, 2013)

emphasise spread as a defining concept, where an invasive species can be defined as:

“...an introduced species that has spread well beyond its arrival point and that perpetuates itself without human assistance” (Simberloff, 2013: 310).

To understand gardeners’ perspectives, it is important to compare ‘invasive’ plants with garden weeds because they share defining concepts (Richards, 2021), including spread. There are also conceptual distinctions between the terms; for example nativeness is irrelevant to the term weed (Richardson et al., 2000; Stace and Crawley, 2015). It should be noted that ‘weed’ is also used within invasion science more broadly to mean invasive, especially beyond Europe, but in Britain & Ireland, ‘weed’ is mostly used in the context of cultivated ground such as gardens (Stace and Crawley, 2015). The term ‘weed’ is subjective (see 1.1.6) but Brickell (2008: 1125) offers a definition of a weed, from a gardening perspective, as a:

“Vigorous, invasive, or self-seeding plant competing with desired garden plants for moisture and nutrients”.

This not only represents the concepts of spread (e.g. self-seeding) but also impact (competition). Power (2005) also found gardeners can define weeds on their lack of functionality. For gardeners, spread can be an issue within their garden and between gardens (Doody et al., 2014; Power, 2005; Saltzman and Sjöholm, 2017), and the spread of invasive species can be considered an example of a gardeners’ interaction with nature (Qvenild et al., 2014).

1.1.4. Impact

Environmental policies (e.g. CBD, 2000; IUCN, 2000) emphasise impact as a defining concept, for example where an invasive species:

“...is an agent of change, and threatens native biological diversity” (IUCN, 2000: 4).

Invasive species can also have economic, human health, or quality of life impacts (IPBES, 2019). For a conceptual framework on invasive species impacts see Kumschick et al. (2012).

It is important to consider what ‘impact’ might mean for gardeners. Because most non-native (including invasive) species were originally introduced intentionally, such as ornamentals (Arianoutsou et al., 2021), many have values (Pascual et al., 2017; Sax et al., 2022) or benefits (Chalmin-Pui et al., 2021; Gaston et al., 2005; Kumschick et al., 2012; Loram et al., 2008; Stelzer et al., 2010; Webster and Culham, 2017). For example, by providing ecosystem services such as resources for pollinators (Salisbury et al., 2015, 2017). For a critical discussion on environmental benefits see Lean (2021). Gardens also offer benefits for human mental and physical health (Dunnett and Qasim, 2000) by providing a setting to connect with nature (Hoyle, 2021; Qvenild et al., 2014; Sax et al., 2022) and the wild beyond. Qvenild et al. (2014) found impact and spread (‘invasiveness’) to be the focus of gardeners’ concerns and not whether a species was native or not.

1.1.5. Control

Definitions of ‘invasive’ do not generally incorporate the issue of control but it is included in environmental policies such as Target 6 (CBD, 2022) of the Kunming-Montreal Global Biodiversity Framework. Control is also an issue for gardeners; Wallington (2020: 10) defines a weed as “a plant that reproduces seemingly uncontrollably”. This represents the concept of spread, and is similar to the Brickell (2008) definition of a weed, but with the additional concept of control (RHS, 2021a). This concept of control within gardens (Power, 2005) is central to whether gardens are considered as separate to nature, where a gardener ‘imposes’ their plans and ambitions by controlling nature, or rather as part of nature where gardeners can engage with nature and potentially attempt to resemble it (Kingsbury, 2005; Power, 2005; Saltzman and Sjöholm, 2017). This distinction becomes especially

nuanced if a species is judged to be a weed, or if a gardener has different ambitions between ‘cultivated’ or ‘natural’ parts within a garden (Doody et al., 2014; Saltzman and Sjöholm, 2017). Furthermore, the act of gardening (e.g. weeding) can be looked at as a reflective learning process (Doody et al., 2014; Power, 2005). A gardener’s judgement is key here.

1.1.6. Judgement

There is arguably an element of judgement (or subjectivity) in the term ‘invasive’ within invasion science (Daehler, 2001; Pyšek et al., 2004) and the aforementioned concepts. This can be a problem when engaging with the ‘publics’ (Estévez et al., 2015) and the term can be emotive (Colautti and MacIsaac, 2004; Golebie et al., 2022; Trudgill, 2008). It is also true that impact can be perceived or judged differently between actors (Estévez et al., 2015; Kumschick et al., 2012; Shackleton et al., 2019; Vimercati et al., 2020). This is clear in the growing recognition of the important benefits of gardens and gardening for human health (e.g. Frumkin et al., 2017; Gross and Lane, 2007; Hoyle, 2021) regardless of whether an ornamental is invasive or not, or indeed its nativeness. The term weed is inherently subjective (Doody et al., 2014; Head et al., 2015; Head and Muir, 2006); colloquially a weed would be described by gardeners simply as a plant growing in the wrong place, or rather where it is not *wanted* (Blatchley, 1912). In the Brickell (2008) definition (see 1.1.3.), a weed is competing with a *desired* ornamental. This could be explained by emotional attachments to specific plants (Head, 2017). Gardeners might also consider garden weeds ‘unwanted’ or ‘uninvited’ in gardens but consider the same species differently in the wild (Clayton, 2007).

1.2. Why is this important?

Defining invasive is not merely a semantic concern because terminology and related concepts are the basis for science communication (Davis and Thompson, 2001; Falk-Petersen et al., 2006; Golebie et al., 2022) and engagement. Inconsistent and inaccurate terminology (Falk-Petersen et al., 2006; Pyšek et al., 2004) might therefore have limitations for science communication and public engagement, and for environmental policy and management efforts (Richardson et al., 2000; Schulz et al., 2021; Westman, 1990). Successful management should involve personal perspectives and attitudes of different actors (García-Llorente et al., 2008; Hulme, 2006; Munro et al., 2019; Selge et al., 2011) and their participation (Gill et al., 2022) to achieve ‘buy-in’ (Selge et al., 2011). Gardeners also have a role in identifying ornamentals with invasive potential (see Dehnen-Schmutz and Conroy, 2018; PlantAlert, 2022) which can enable early detection (Roy et al., 2014). This is important in achieving Target 6 (CBD, 2022) of the Kunming-Montreal Global Biodiversity Framework.

Hulme et al. (2017) discussed four policy instruments for the ornamental horticulture industry to reduce the spread of invasive species: pre-border import restrictions, post-border ‘sales bans’, industry code of conduct and consumer education. The four policy instruments are possible interventions for encouraging environmentally sustainable behaviour (Steg and Vlek, 2009) and should ideally be integrated (Hulme et al., 2017). How gardeners define or understand ‘invasive’ is important because of how they interpret relevant environmental policies - for an example see Cerri et al. (2022) - and has implications for the four instruments but the focus here is on consumer education.

Consumer education can raise awareness, or increase environmental knowledge (*sensu* Kollmuss and Agyeman, 2002) and influence opinions (Golebie et al., 2022) of invasive species and their impacts to encourage behavioural change (Hulme et al., 2017). There are challenges to consumer education (see Hulme et al., 2017) including ambiguity in terminology and the tendency to consider consumer education as one directional. This arises from an assumption (the knowledge-deficit model) that science communication alone will increase awareness of a problem and result in behavioural change (Cook and Melo Zurita, 2019;

Schultz, 2002; Sturgis and Allum, 2004). This assumption has long been challenged (Cook and Melo Zurita, 2019; Head, 2017; Tassin and Kull, 2015) not least for being too simplistic (Sturgis and Allum, 2004) and because behaviour such as plant choice (Hu and Gill, 2016) is determined by many factors (Kidd et al., 2019; McKenzie-Mohr, 2011) including attitudes (see Maller, 2021). It would be better to aim for a “two-way flow of knowledge” (Shackleton et al., 2019: 88) or information through dialogue (i.e. engagement). Moving beyond the knowledge-deficit model (Jacobson et al., 2015; Kidd et al., 2019) could result in a better understanding of how gardeners interpret environmental policies, and the motives and factors for choosing (or not) to adopt environmentally sustainable or ‘pro-environmental’ behaviour (see Kidd et al., 2019) while gardening (Clayton, 2007; Hu and Gill, 2016; Kiesling and Manning, 2010; Kollmuss and Agyeman, 2002; Lange and Dewitte, 2019; Steg and Vlek, 2009). For example, this is more likely if a gardener has direct experience of managing invasive species in the wild (Hulme et al., 2017; Merenlender et al., 2016) which links to their connection (or lack of) with nature (Kidd et al., 2019; Nisbet et al., 2009; Schultz, 2002). A gardeners’ connection with nature can shape their attitudes and behavior towards nature (Clayton, 2007; Hoyle, 2021) but this is influenced by many factors (Barr, 2008; Kidd et al., 2019). For engagement to succeed in encouraging behavioural change, focus should be put on enabling gardeners to meaningfully (rather than superficially) participate (Cook and Melo Zurita, 2019). For example, by asking gardeners directly how they define ‘invasive’ rather than this be determined by experts (Cook and Melo Zurita, 2019) in invasion science and environmental policies. Consumer education as an instrument would therefore be better and more effective if approached as engagement, with science communication as a potential first step (Kidd et al., 2019). This needs an understanding of how gardeners define the term ‘invasive’.

There have been studies looking at perceptions of different actors towards invasive species (e.g. García-Llorente et al., 2008; Humair et al., 2014), gardeners’ awareness of the term (Palmér et al., 2023; Qvenild et al., 2014) and their behaviours (e.g. Hu and Gill, 2016), but few in Britain & Ireland. Furthermore, to the authors’ knowledge no studies have asked gardeners directly how they define ‘invasive’, and compared this to definitions used within invasion science and environmental policies. This is explored here and should inform science communication and public engagement efforts and empower the 30 million gardeners in Britain (RHS, 2021b) to improve the environmental sustainability of gardening by being the ‘first line of defence’ against invasive species. To do this, the study looks at:

1. How do gardeners define the term ‘invasive’?
2. What are the implications for environmental policy instruments?

2. Materials and methods

2.1. Gardeners’ survey at Chelsea

Gardeners were asked in a survey, ‘How would you define an invasive plant?’ which was an optional free-text question with no limitations set on responses. The Chelsea survey was hosted by Jisc Online Surveys and approved by the Ethics Committee of the School of Biological Sciences at the University (reference number SBS18-19 36). Survey respondents gave their informed consent (as part of the survey) to participate and for anonymised results to be used in published research.

The Chelsea survey was launched at the Discovery Zone (RHS, 2019) of the Royal Horticultural Society (RHS) Chelsea Flower Show (‘Chelsea’) in May 2019, with an educational exhibit (Fig. 1) called ‘Ornamental plants: our future invaders?’. This was a collaborative project at the University of Reading. The Discovery Zone is a space for visitors to engage and learn about horticultural topics and research (RHS, 2019). The exhibit was judged by the RHS using their Lindley judging criteria for educational exhibits and awarded a gold medal.



Fig. 1. Visitors engaging with the gold medal winning exhibit ‘Ornamental plants: our future invaders?’ at the RHS Chelsea Flower Show in 2019. Photo credit: British Ecological Society (2019).

The exhibit (Fig. 1) was planted with ornamentals previously reported by gardeners in Britain & Ireland, as part of an unpublished pre-Chelsea survey. A careful selection of those ornamentals represented different stages of the invasion process (Blackburn et al., 2011) and possible impacts of climate change on invasive potential. As a science communication and public engagement project, it explained the issue of invasive plants and the role of gardeners. Volunteers (staff and students) from the University were present to engage and facilitate dialogue with visitors. Particular definitions of invasive were offered as part of the exhibit: as having a “damaging effect on the environment” and a “detrimental impact on native species” which was necessary to serve its science communication purpose.

Visitors could complete the Chelsea survey on electronic tablets, either independently or with a trained staff or student member from the University. The target audience for the Chelsea survey were amateur and professional gardeners; to be eligible to participate each visitor had to self-identify as a gardener in Britain or Ireland. The sampling method can be described as non-probability (Callegaro et al., 2015; Vehovar and Manfreda, 2017) convenience sampling (*sensu* Vehovar and Manfreda, 2017) which is common for such surveys. The Chelsea survey was then made available online. This was publicised on social media (e.g. #GardenEscapers on Twitter) - still with convenience sampling - and closed in December 2019. The study was not looking at getting a representative sample of gardeners, and the results should be considered in this context. It was also not practical due to the character of the show to require visitors to participate in the survey before engaging with the exhibit.

2.2. Data analysis

Thematic analysis was used to identify themes within and between responses (Braun and Clarke, 2006; Gibbs, 2011; Guest et al., 2012; Hillier et al., 2021; Vaughn and Turner, 2016). A deductive approach (Braun and Clarke, 2022; Braun and Clarke, 2006; Guest et al., 2012;

Kvale and Brinkmann, 2009) used the six concepts, mentioned in the introduction (Section 1.1.) and being common in invasion science and environmental policies, as themes: ‘nativeness’, escape, spread, impact, control and judgement (or subjectivity). This approach of having *a priori* themes was deemed appropriate because of the direct comparison with how ‘invasive’ is defined by invasion scientists and in environmental policies. The thematic analysis was an adaptation of that of Archer and DeWitt (2021) as explained in Table S1 and S2. An example is shown in Fig. 2 with simultaneous coding (Saldaña, 2015) and further responses are included as quotations in the discussion.

2.3. Statistical analysis

The ‘UpSetR’ package (Conway and Gehlenborg, 2019) and ‘eulerr’ package (Larsson et al., 2020) were used in RStudio version 4.0.4 (R Core Team, 2021) to analyse the results of the thematic analysis.

3. Results

An estimated 12,000 people visited our exhibit at Chelsea. Of the 234 responses to the question relevant to this study, 201 were retained for analysis after geocoding (to ensure responses were from Britain or Ireland) and one incoherent response was removed. Of the retained responses, 69 were given by visitors at Chelsea with the remaining responses given online. Offering the Chelsea survey online increased the number of responses and demographic representation, constituting a higher relative proportion of respondents especially for those aged 18–54 (Fig. 3). This was also true for respondents aged 75+, which might be because it was more accessible for them than visiting the show.

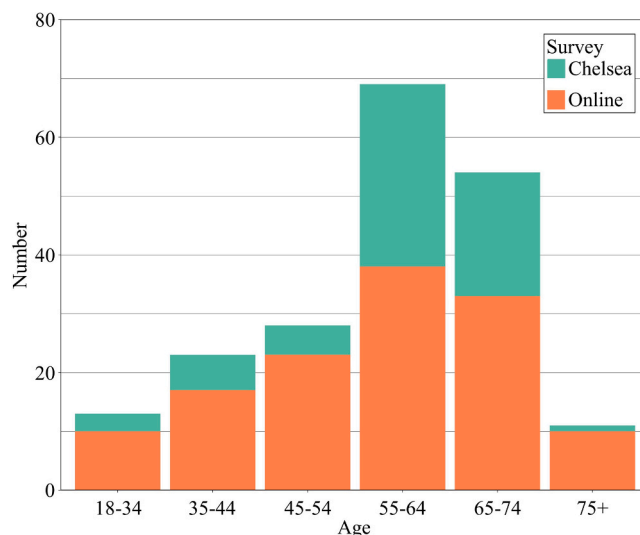


Fig. 3. Age profile of respondents to the survey question ‘how would you define an invasive plant?’ for visitors at Chelsea [n = 67] and online responses [n = 131]. Only respondents who gave their age [n = 198].

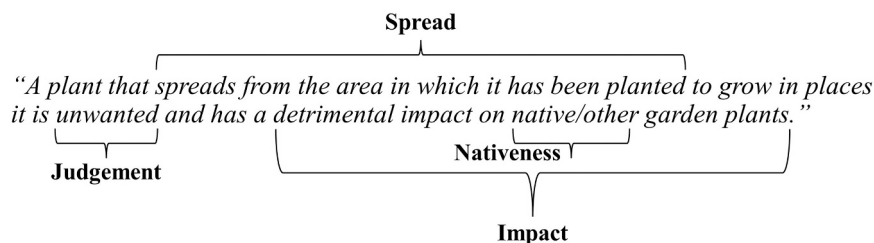


Fig. 2. An example of the thematic analysis of a response to the survey question ‘how would you define an invasive plant?’. The response has been aligned to a combination of four themes.

The purpose of this study was not to compare different definitions of ‘invasive’ amongst different gardeners. The following discussion does therefore not consider how the responses might differ with age, but it is important to recognise that the Chelsea survey represented gardeners of a range of ages. Fig. 4 shows the geographic representation of respondents. There were no responses from the Republic of Ireland or Northern Ireland.

Responses ranged in complexity, for example in their length from a single word, “weed”, to 57 with an average of 14 words. There were also differences in complexity in how many themes each response was aligned to (i.e. how many concepts the response contained representing a theme). The simplest responses, aligned only with one theme, totaled 57: **nativeness** = 3, **judgement** = 3, **control** = 13, **impact** = 17, **spread** = 21 and no response was aligned only to **escape** (Fig. 5). There was then increasing complexity (alignment) with the single most complex response being aligned with five themes. The full list of responses and their theme alignments are presented in Table S3.

Fig. 5 shows the results of the thematic analysis, where ‘intersection size’ represents the number of responses aligned with each theme, or combination of themes, and ‘set size’ represents the total number of responses aligned with each individual theme (regardless of any combination). **Spread**, **impact**, and **control** represented the most responses aligned only to one theme (Fig. 5, ‘intersection size’) as well representing the most responses (Fig. 5, ‘set size’) with a total of 124, 92, and 76 responses, respectively. The most common relationships [$n = 32$] were between themes **spread** and **control**, followed by **spread** and **impact** [$n = 17$].

The different combination of alignments represents different definitions of invasive. The results are also summarised in Fig. 6 as a Eulerr diagram (see Fig. S1 for the error plot).

Individual responses (with response IDs) are used in the following discussion but see Table S3 for a full list of the responses and their alignment.

4. Discussion

4.1. How do gardeners define the term ‘invasive’?

This study has shown that gardeners define ‘invasive’ using many of the concepts within invasion science and environmental policies. For example, **spread** and **impact** were the main defining concepts for gardeners, as in the general conceptual distinction between invasion science (e.g. Blackburn et al., 2011; Richardson et al., 2000) and environmental policies (CBD, 2000; IUCN, 2000). This is supported by evidence of commonality (albeit nuanced) between ‘experts’ and the publics (Head, 2017) and suggests that inconsistent and inaccurate use of terminology in invasion science (Falk-Petersen et al., 2006; Pyšek et al., 2004) and environmental policies does not limit science communication and engagement efforts. Yet this could be challenged with the nuances that have been found in gardeners’ definitions of invasive which are discussed here.

Spread and **impact** being the main concepts could be attributed to a common usage of the word ‘invasive’, but it is clear in responses aligned with **impact** that gardeners considered ecological and/or economic

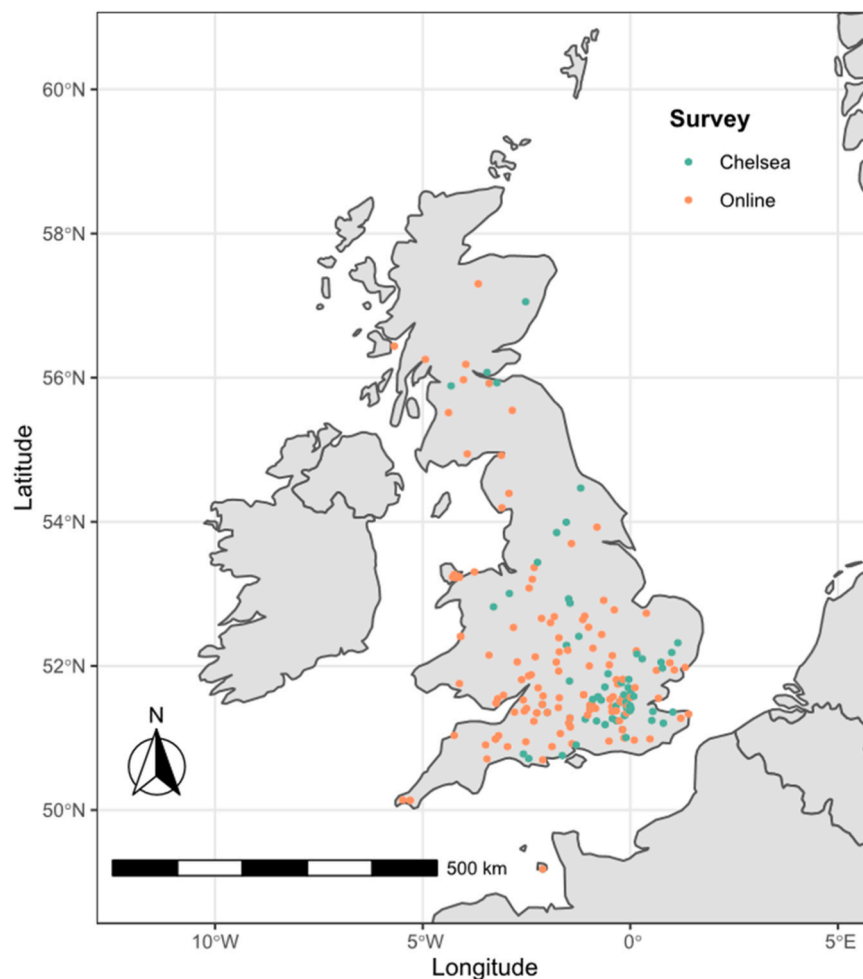
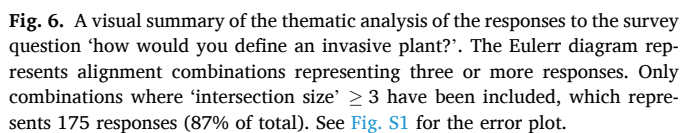
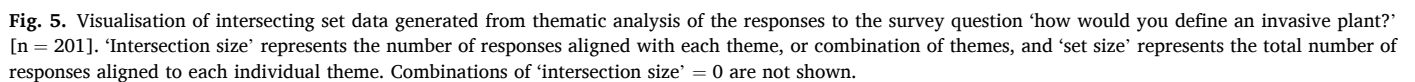


Fig. 4. Geographic distribution of responses to the survey question ‘how would you define an invasive plant?’ for visitors at Chelsea [$n = 69$] and online responses [$n = 132$].



gardeners and invasion science and thus better mutual understanding of 'invasive', than with environmental policies. It is important to consider the responses within the context of Chelsea, where particular definitions of invasive were offered as part of the exhibit including having a "*detrimental impact on native species*". This might be reflected in three responses which include the word 'detrimental'.

Critically, a difference in understanding was found on *where* the term 'invasive' was applied, and the associated concepts especially **spread** and **impact**. One gardener made a clear distinction:

"One which spreads into the wider environment outside gardens (or outside its native country) and outcompetes other flora; within gardens, one which spreads quickly via seed or underground, and/or is difficult to eradicate" (478260-478251-47379769).

There is a difference in emphasis here between the ‘wider environment’ - similar to ‘the wild’ of Blackburn et al. (2011) - and gardens. For the former, their definition of ‘invasive’ incorporates the concept of **spread** of invasion science (e.g. Richardson et al., 2000) and **impact** of environmental policies (IUCN, 2000; Weber, 2003). For most gardeners, their responses applied (implicitly or explicitly) to gardens. A similar point was found by Qvenild et al. (2014) in Norway. This shows that although our study found common concepts, how gardeners apply the concepts can be spatially specific (Head, 2017; Head and Muir, 2004). This also demonstrates how some gardeners separate the garden and ‘wild’, and that this gardener (478260–478251–47379769) at least considers their garden separate to nature (Kingsbury, 2005; Power, 2005; Saltzman and Sjöholm, 2017).

For gardeners, **spread** was mostly a concern within their garden if a plant “*doesn't stay in one place*” (477924–477915–47416271), which is different to how it is used within invasion science (e.g. Richardson et al., 2000). A consequence of **spread** is often the need to **control**. Although this is not a defining concept within invasion science, it is an aspect of environmental policies. **Control** was also important for gardeners. For example, the strongest commonality (Fig. 5) was between **spread** and **control**. Gardens often have specific aesthetic or visual expectations

(Kiesling and Manning, 2010; Power, 2005), with control being a fundamental part of gardening (Power, 2005). One gardener defined ‘invasive’ as a plant “*spreading into areas where it’s not intended [or] desired to grow*” (478260–478251–47785670). This response also demonstrates the strong commonality between **judgement** and **spread**. Of those responses aligned with **control**, at least one gardener (478260–478251–48348487) suggested this had been a reflective process (Doody et al., 2014; Power, 2005): “*A plant that I have been unable to eradicate from my garden*”.

Most of the responses aligned with **nativeness** agreed with invasion science and environmental policies in specifying explicitly that invasive plants are non-native. Of the responses aligned with **nativeness**, most (Fig. 6) were also aligned with **impact**. This might suggest that impact, rather than nativeness itself (Qvenild et al., 2014), was the main defining issue (Head, 2017; van Der Wal et al., 2015) for those gardeners. One gardener specifically excluded “*native plant[s] like bracken*” (478260–478251–52993986). However, another gardener alluded to native invaders:

“allegedly it is plants which are not native but I would happily use the phrase [invasive] about native plants e.g. bramble.” (478260–478251–47555247).

Three responses equated invasive to mean non-native or “*not naturally found*” (477924–477915–47306641) with no indication of **impact** or **spread**. Another example was, “*a non-native species which Dickens would not be familiar [with]*” (477924–477915–47444600). This brings in the issue of temporal scale, which was also present in another response which considered an invasive plant to be “*recently introduced*” (478260–478251–47339299). This differs to how non-native is most commonly defined in invasion science and environmental policies. Responses aligned with **nativeness** also raised the issue of spatial scale with seven gardeners specifying habitat as the scale of interest, not country. Head and Muir (2004) also found nativeness to rarely be (explicitly) linked with a geopolitical boundary.

The issue of **nativeness** was not confined to the status of the plant itself, but also whether it impacted native biodiversity specifically (IUCN, 2000; Weber, 2003). One gardener wrote “*a plant that out-competes native or other desired flora*” (478260–478251–47785670), bringing in the issue of **judgment** of what is desired. One gardener made a direct comparison between an invasive plant and a weed:

“whereas the definition of a weed is a plant in the wrong place, the definition of an invasive plant is one that “refuses” to remain in its allotted space and insists on taking over everyone else’s space!” (478260–478251–47783466).

Their definition of a weed matches the colloquial meaning (Blatchley, 1912) but does not consider any lack of functionality (i.e. use) to define a weed (Power, 2005). It is possible that gardeners have become sensitised to the issue of invasive species but are inadvertently conflating this with weeds. Three gardeners defined an invasive species simply as a weed. This, along with **nativeness** itself not being a defining concept, means it would be useful to ask gardeners to explicitly compare their understanding of invasive species and weeds.

The gardener (478260–478251–47783466) went on to add “*I grow many of them in my garden and describe them as beautiful ‘thugs’, but they are high maintenance plants!*”. Describing them as beautiful is interesting, because most invasive plants were introduced originally for their value as ornamentals (Sax et al., 2022; Stace and Crawley, 2015). This was the only recognition of ecosystem services (cultural service) and values (Salisbury et al., 2015, 2017; Sax et al., 2022). By describing them as beautiful the gardener is suggesting their aesthetics is a more important factor than **control** and **spread**. This is one reason why it is important to effectively communicate the issue of invasive species to gardeners, because many of these species continue to be popular due to their values (Sax et al., 2022), including aesthetic as ornamentals. This gardener also, by having an “*allotted space*” suggests they have different

ambitions of plants for different parts of the garden (Doody et al., 2014; Saltzman and Sjöholm, 2017) thus **spread within** the garden is an issue (Doody et al., 2014; Power, 2005; Saltzman and Sjöholm, 2017).

Prominent within responses aligned with **judgement** was the issue of a plant being unwanted or unwelcome, suggesting also a disconnect between gardens and nature (Clayton, 2007). Is this due to a plant’s attributes (i.e. traits), or rather the negative connotation associated with ‘invasive’? Gardeners using ‘unwanted’ implied that this was because the plant **spread** and/or was difficult to **control**, such as being “*fast growing, virtually indestructible, unwanted*” (478260–478251–48399930). Despite the growing appreciation of weeds for gardens (e.g. Richards, 2021; Wallington, 2020), no evidence was found of the weeds being desirable, or encouraged in gardens. Neither was any evidence found, as by Qvenild et al. (2014), of invasive species being appreciated for being ‘easy’ to grow (Doody et al., 2014; Hitchings, 2003, 2007; Saltzman and Sjöholm, 2017).

For an ornamental to have an impact it will have needed to **escape** from gardens. Despite this important point, only five gardeners explicitly mentioned ornamentals escaping gardens. These gardeners defined **escape** as a necessary step before a plant could become invasive. For example, “*a plant that has been introduced and has escaped the garden habitat to become a problem in the wider environment*” (478260–478251–47912177). **Escape** - although normally unintentional through natural means - can also be intentional if plants are “*dumped in the wild*” (478260–478251–50628017). Colonisation was reflected in seven responses; six of these suggested that colonisation meant a plant successfully escaping gardens. The issue of **escape** was also ‘flipped’, for example: “*[a plant] that colonises from outside and multiplies quickly and is very difficult to remove*” (477924–477915–47317082). Here the gardener suggests that it is, along with **spread** and **control**, a concern when a species spreads into the garden (Doody et al., 2014; Power, 2005; Saltzman and Sjöholm, 2017). **Escape** was a complicated concept because not a single response was aligned exclusively to this theme. Similarly, only three of the responses aligned with **judgement** or **nativeness** were unique to either theme. For the latter, this might concur with Head and Muir (2004) who found nativeness and invasiveness to be commonly decoupled, but importantly environmental policies consider invasive species *a priori* non-native. This strongly suggests that these three concepts of **escape**, **judgement** and **nativeness** - although important in how gardeners define invasive - are not defining concepts compared with **spread**, **impact** and **control**.

By exploring the connections between the concepts, this study has demonstrated the nuanced perceptions and definitions of ‘invasive’ amongst gardeners in Britain, which is not merely a semantic exercise but has implications for invasion science. Mainly, in identifying the distinction between how gardeners can consider the term differently in garden and the wild. The distinction is crucial because it is not *necessarily* species which are problematic within gardens (e.g. weeds) which are a concern but those which are (or might) escape gardens. This suggests a need to better explain the impacts of invasive species in the wild, and the connection with gardening.

An inductive approach to the thematic analysis, allowing themes to emerge from the responses, might have given a deeper understanding but the deductive approach has worked well in this study because of the direct comparisons with how ‘invasive’ is defined within invasion science. The implications for environmental policy instruments are discussed below.

4.2. What are the implications for environmental policy instruments?

This study on gardeners’ definition of invasive has important implications for environmental policies on invasive species including the four policy instruments of Hulme et al. (2017). Here, how mutual understanding of ‘invasive’ through science communication and public engagement would benefit each instrument is identified with a focus on engaging with gardeners.

4.2.1. Pre-border import restrictions and post-border 'sales bans'

There is a direct flow of ornamentals between imports at borders and gardeners (Hulme et al., 2017), such as through (legal and illegal) online trade. Restrictions and 'sales bans' can often be ineffective, due partly to communication challenges (Qvenild et al., 2014) if gardeners do not know which species are listed (Cerri et al., 2022). Achieving mutual understanding - or at least considering different definitions - would help implement such environmental policies. For example, by labelling a plant as 'invasive', it is important that gardeners understand exactly what is meant by that and the implications for their behavioural change such as plant choice (Hu and Gill, 2016).

Gardeners can also help identify ornamentals with invasive potential (Dehnen-Schmutz and Conroy, 2018) as a preventative approach (Hulme, 2006). However, for this to be effective in achieving early detection there needs to be a mutual understanding of 'invasive'. Specifically, the differences in defining an invasive species and weeds needs to be understood (PlantAlert, 2022) and the distinction between gardens and the wild. Bridging this distinction, although nuanced, could mean a huge improvement in early detection of ornamentals with invasive potential. There is also a need to focus on limiting the spread of invasive species (Hulme et al., 2017) through at least one of the following two instruments.

4.2.2. Industry code of conduct

Voluntary codes of conduct (e.g. Heywood and Brunel, 2011) can arguably only be effective if there are consequences for not complying, such as by impacting negatively on public reputation (Hulme et al., 2017). This could also be supported by instigating a change in consumer choice (Hulme et al., 2017) or behaviour which would reduce the demand for invasive species. This again requires gardeners to know which species are invasive (and not to grow) and the threats they pose (IPBES, 2019) so that they can notice non-compliance. This can be achieved through engaging with gardeners.

4.2.3. Engaging with gardeners

Educating gardeners (Hulme et al., 2017) through effective science communication, or better, engagement can encourage environmentally sustainable behaviours (see Kidd et al., 2019) while gardening (Clayton, 2007; Hu and Gill, 2016; Kiesling and Manning, 2010; Kollmuss and Agyeman, 2002; Lange and Dewitte, 2019; Reichard and White, 2001; Steg and Vlek, 2009). This could also have a 'trickle' effect with gardeners encouraging others to consider the impacts of invasive species (Kiesling and Manning, 2010). Approaching this as an engagement (be it meaningful or superficial) rather than education is an important opportunity to explore the factors determining behaviours (Kidd et al., 2019; Maller, 2021; McKenzie-Mohr, 2011). This could be for individual gardeners, but engagement could also be achieved by involving horticultural societies and gardening clubs, nurseries and garden centres with the opportunity to reach more gardeners.

Understanding how gardeners define 'invasive' can help invasion scientists explore the factors determining behaviours, which is particularly important to go beyond raising awareness towards influencing behavioural change more effectively. This could also be more effective than the aforementioned 'top down' instruments (Kendal et al., 2012). This study has three clear implications for exploring gardeners' behaviour in relation to invasive species, including choice of approach to encouraging behavioural change (Kidd et al., 2019: 1) gardeners' distinction between the garden and the 'wild' and their possible (dis)connect with nature; 2) **nativeness** not being a main defining issue; and 3) the difference and similarities for gardeners between weeds and invasive species.

5. Conclusion

Similarities were found in how gardeners define 'invasive' and how it is defined in invasion science and environmental policies, especially

with the two concepts of **spread** and **impact**. There were also clear differences; for example, **control** was the singular defining issue for gardeners and impact was not confined to the 'wider environment' or wild. Importantly, most gardeners only considered the term invasive specifically *within* their gardens. Both points have important implications for engaging gardeners with invasion science and relevant environmental policies including limiting the spread of ornamentals currently regarded as invasive species, and early detection of those with invasive potential (Roy et al., 2014).

This study does not claim to have enabled gardeners to meaningfully participate (Cook and Melo Zurita, 2019). Rather, by engaging with gardeners and asking them directly how they define 'invasive' and exploring the similarities and differences with invasion science and environmental policies, it is hoped this will inform further research on how to empower the 30 million gardeners in the UK to adopt a change in behaviours through meaningful engagement. It is evident from experiences in engaging with gardeners (including at Chelsea) that they are willing to embrace this and have an interest in their role in the issue of invasive species. Further research should focus on from where and how gardeners obtain their knowledge or awareness of invasive ornamentals, including how to reach gardeners most effectively. Also, to explore how gardeners' understanding of the term 'invasive' can inform the factors determining behavioural change and its implementation through the environmental policy instruments.

Ethics approval

The research was approved by the Ethics Committee of the School of Biological Sciences at the University of Reading (reference number SBS18–19 36).

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CRedit authorship contribution statement

The research project was conceived by Alastair Culham and Eleanor Webster (previously at the Royal Horticultural Society). Tomos Siôn Jones conceived the idea for the manuscript. Study design, material preparation and data collection were performed by Tomos Siôn Jones and Alastair Culham, with Brian John Pickles contributing to the analysis. The first draft of the manuscript was written by Tomos Siôn Jones and all authors commented on each version of the manuscript. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data generated or analysed during this study are included in this published article (and its Supplementary Material).

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Consent to participate

Survey respondents gave their informed consent to participate in the survey.

Consent for publication

Survey respondents gave their informed consent for anonymised survey results to be used in published research.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.envsci.2023.103614](https://doi.org/10.1016/j.envsci.2023.103614).

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