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Working with gardeners to identify potential invasive ornamental garden plants – testing a citizen science approach

Katharina Dehnen-Schmutz & Judith Conroy*

Centre for Agroecology, Water and Resilience, Coventry University, Ryton Gardens, Coventry, CV8 3LG, UK

*Corresponding author, email ab6340@coventry.ac.uk, telephone 0044 2477 651 612, Orcid ID: orcid.org/0000-0001-5782-7488

Abstract

The introduction and use of ornamental plants in gardens is the main pathway for plant invasions globally. High numbers of ornamental plants in gardens may not have started an invasion process yet and are a risk for possible future invasions. Gardeners could be among the first to notice plant traits that have also been recognised to contribute to the potential risk of ornamental plants to escape from cultivation. We asked gardeners in Britain to report ornamental plants that were spreading within their gardens and difficult to control using an online survey. Gardeners submitted 201 records of 121 species of which 104 are non-native in Britain. Most non-native species reported were already recorded and wide-spread in Britain outside cultivation, but about a third are not widely distributed, and eight species are not known outside cultivation.

Gardeners' control efforts were mainly directed to confine plants from further spread, but they also tried to eradicate many of the reported plants. Our results provide evidence that gardeners' knowledge could help to identify potentially problematic invasive plants early in the invasion process. Even with low levels of participation all evidence collected would be very valuable in official risk management procedures as well as supporting legal obligations on early detection, surveillance and monitoring. At the same time, however, raising awareness of the problem by actively collaborating with gardeners could be of equal importance for the prevention of ornamental plant invasions in the future.

Keywords: ornamental plants; plant invasion; citizen science; garden; horticulture; non-native plants; Great Britain

Introduction

The deliberate introduction and use of non-native plants for ornamental horticulture has been identified as the most important pathway for plant invasions globally (Kowarik 2005; Hulme et al. 2008; Saul et al. 2017; Hulme et al. 2018). This is reflected in national floras. For example, of 2500 non-native species in the British Flora almost half (1195) are horticultural introductions (Stace and Crawley 2015) and in South Africa, of 344 alien species with known pathways 86% were escaped from cultivation (Faulkner et al. 2016). Increasing trade of "plants for planting", emerging new trade relationships, and increasing numbers of species marketed as ornamentals are all likely to expand the importance of the pathway in the future (Bradley et al. 2011; van Kleunen et al. 2018). Current policy responses seem to be mostly insufficient to deal with the problem in particular with regard to pro-active measures (Early et al. 2016; Seebens et al. 2017). Prevention policies targeting potential new plant introductions may also miss the large number of non-native species already cultivated in gardens. Given the number of species involved – in Britain alone more than 72 000 taxa (species and cultivars) are traded (Armitage et al. 2016) – risk assessments and screening procedures may prove too lengthy and costly to be conducted proactively at this scale (Dehnen-Schmutz 2011). Long delays from the introduction in a garden to the recognition of a problematic invasive plant in the wild make effective control strategies very difficult and often impossible. This "invasion debt" (Essl et al. 2011) is likely to be accelerated by climate change which could trigger invasion processes of plants previously not considered fully hardy (Dullinger et al. 2017). Previous research has shown that propagule pressure is a key factor in invasion success (Lockwood et al. 2005) with plants more widely sold and planted being more likely to establish outside cultivation (Dehnen-Schmutz et al. 2007b, a).

However, little is known about ornamental plant species diversity in parks and private gardens, and few studies have accessed private gardens cataloguing them. For example for the city of Sheffield, UK, Smith et al. (2006) provided an inventory of the entire flora of 61 private gardens where 70% of the 1166 species recorded were non-native. A similar inventory of 178 private and public gardens in the Czech Republic recording only species planted for ornamental purposes found 1642 species of which 77% were non-native (Pergl et al. 2016). These studies are very useful because they provide data on the frequency of planting of ornamental plants that can be used as a measure of propagule pressure essential for the establishment success of these species outside gardens. However, they do not provide information on the possible naturalisation of species already happening in gardens. Private gardens are difficult to access for researchers, and in cases where access is possible these are often single visits insufficient to collect information on possible invasiveness of plants that may be disguised by garden management. Gardeners strive to provide the best achievable growing conditions for their cultivated plants (Mack 2000) but also control and contain those plants that may otherwise dominate plantings. They could therefore be among the first to notice plant traits that have also been recognised to contribute to invasion success, such as fast and vigorous spatial growth, earlier and better germination, higher survival of seedlings and long flowering periods (Pyšek and Richardson 2007). Similarly, problems with removing plants they no longer want in their gardens could indicate potential control problems in cases where such plants would establish outside gardens.

The main purpose of this paper was to test if a citizen science approach involving gardeners could provide species specific information that would go beyond data collected in the usual recording schemes from outside gardens. Citizen science has

become increasingly popular in recent years both for recording wildlife in gardens (Foster et al. 2017) and to record invasive species (Adriaens et al. 2015; Cardoso et al. 2017). However, the focus of projects in invasion science so far has been on recording alien species that are already confirmed outside cultivation or well-known invasive species (Gallo and Waitt 2011; Roy et al. 2015). Here, we report results of a project that to our knowledge for the first time involves gardeners in the reporting of early signs of potential invasiveness in gardens.

We asked gardeners to report ornamental plants that are spreading and difficult to control in their gardens. If gardeners were to just report plants that are already widely reported outside gardens the approach may not add much additional information. We also asked how the plants reported had come into their gardens, about their management, and where new plants were sourced from. For species where outside records already existed we examined their current distribution and recent changes in distribution and related these data to the management data received from gardeners. We used our results to identify policy options most useful to be adopted to for the prevention of future ornamental plant invasions.

Materials and methods

Survey design and survey link distribution

The Internet based survey was developed using the Bristol online survey tool (https://www.onlinesurveys.ac.uk/). The questionnaire (Supplementary material 1) first acknowledged the contribution of non-native ornamental plants to people's enjoyment of gardens and gardening as well as their important role in contemporary and historic garden designs. After a short explanation about the problem of some ornamental plants becoming invasive outside gardens and their potential negative

impacts on native biodiversity participants were then told about the crucial role gardeners could play identifying those ornamentals plants with a potential risk to become problematic invaders outside gardens. In the next section respondents were asked to name up to five ornamental plants that were spreading in their garden and were difficult to control. For each plant, they could also provide a score of their plant identification confidence (1 = very sure; 2 = not really sure; 3 = could be wrong), how they were spreading in their garden, their methods of control, the disposal of plants, and how the plants came into their garden. To capture control effort, they were asked to choose from a list of five statements the one that would best describe their effort. The final section included questions about their plant acquisition behaviour, garden size, age of residential area and location (postcode). The survey was anonymous but people were asked to leave an email address for potential clarifications and if they wanted to be informed about the survey results. The survey was approved by Coventry University's ethics committee.

The survey link was distributed by email and social media (twitter accounts: @bsbibotany, @jcgardener; BSBI Facebook page; shared on various gardening groups' Facebook pages through one of the author's private profile). In particular, collaboration with the Botanical Society of Britain and Ireland (BSBI) through their blog, a poster at their annual meeting, vice-county recorders' newsletter, and twitter account helped to spread the survey link. The survey was open from November 2015 to April 2016 and aimed at a British audience only.

Data base

The survey data were assembled into a database and first checked against the Distribution Database of the Botanical Society of Britain and Ireland (http://bsbidb.org.uk/) for potential species' records in Great Britain. If records

existed, we noted the number of hectads (10 km^2) in which the species was recorded for the period up to the year 1999 which was the cut-off year for the publication of the New Atlas of the British and Irish Flora (Preston et al. 2002) involving a major recording effort, and all records from 2000 to the completion of our database in July 2016. The global naturalisation status of the species was checked by continent in the Global Naturalized Alien Flora (GloNAF) database (version 1.1, van Kleunen et al. 2015; Pyšek et al. 2017). The status of species as native or alien in Britain was determined from Preston et al. (2002) and data on the continent of origin of species were taken from Stace and Crawley (2015). All native species were excluded from further data analysis.

We used the 2016 online edition of the Royal Horticultural Society's Plant Finder (https://www.rhs.org.uk/Plants/Search-Form accessed June 2016) to add the number of nurseries currently offering the plants for sale as a measure of popularity. The nomenclature follows The Plant List (http://www.theplantlist.org/). If cultivars/varieties of species were reported we used distribution data at the species level unless the BSBI database provided records for the cultivar. Records marked by respondents as "not really sure" for their plant identification were accepted in the database, whereas records marked as "could be wrong" were verified with the respondents if possible.

Data analysis

The number of occupied hectads was logit transformed (= log(p/q), where p is the proportion of hectads occupied out of the total 2837 in Great Britain and q the proportion unoccupied) to account for the finite size of the area of investigation (Williamson et al. 2009). We used the proportional increase in the number of occupied hectads from up to the year 2000 to 2016 as a measure of change in

distribution over that period (in three cases with zero records before 2000 these were set as one). The significance of differences in species distribution as measured in the number of hectads, the relative change in distribution and number of nurseries selling species in relation to pathways of their introduction into the gardens were compared using Kruskal-Wallis tests and Chisquare tests in R (Version 3.1.2; R Core Team 2015). For species recorded from more than one garden the dependent variable was multiplied by a weighting variable defined as 1/number of records so that species with numerous records were not disproportionately represented in comparison to species with few records.

Results

Fifty-six respondents from all over the UK (map in supplementary appendix 2) filled in the survey reporting an average of 3.6 spreading plants difficult to control and a total of 201 records. These records were from 121 species of which 17 are native in Britain (species list in supplementary appendix 3). For eight species, cultivars were reported and two of these had records outside gardens. Records for 18 plants were at the genus level only. Respondents were confident that they provided the correct plant identification and in only 11 cases reported they were not really sure or could be wrong (8 records, 2 not confirmed and analysed at genus level).

Thirty-two species have been reported by more than one gardener, with *Anemone scabiosa* ("Japanese Anemones"), *Crocosmia x crocosmiiflora, Hyacinthoides hispanica*, and *Lamium galeobdolon* subsp. *argentatum* the most frequently reported species from six gardens each. However, *Crocosmia* spp. is the most frequent plant with a further four records reported at the genus level.

Eight species have not been recorded outside cultivation (Table 1), and four of these are listed as naturalised outside their native range in other parts of the world in the GloNAF database (van Kleunen et al. 2015; Pyšek et al. 2017). Thirty-two species have a current distribution of less than 100 hectads in Britain.

For all species with records outside cultivation an increase in occupied hectads since the year 2000 was observed with three species having their first record after this year (*Aster x frikartii* 'Mönch', *Geranium x oxonianum* 'Claridge Druce', and *Mentha longifolia*). For testing the relationship between the number of times a species was reported with its distribution outside gardens (= number of occupied hectads) we combined all records of species with four and more records into one category of four species because of the small numbers of species. Using the resulting four groups, we found no significant difference in the distribution of species outside gardens (Kruskal-Wallis chi-squared = 4.48, df = 3, p-value = 0.22) nor in the relative increase since the year 2000 (Kruskal-Wallis chi-squared = 1.21, df = 3, p-value = 0.8).

Most plants reported were already in the garden when the respective respondent had moved into the property. Figure 1 shows that these species were also more likely to be species with a more frequent distribution outside gardens whereas five of the eight plants not occurring outside had been bought by the respondents themselves. A Kruskal-Wallis test comparing these pathways into gardens with regard to the distribution of species outside gardens measured in number of occupied hectads confirms the significant differences (Kruskal-Wallis chi-squared = 13.91, df = 5, p-value = 0.016), also if the category “already in the garden” was excluded given the uncertainty of this pathway related to the fact that people may have moved into their homes at different times (Kruskal-Wallis chi-squared = 12.6, df = 4, p-value = 0.0134). Further pathways pointed out by respondents were plants arriving in a pot

with another plant bought in a nursery, from compost, and own collection in the wild ("*found it dumped by roadside and thought 'that's a pretty geranium'. Stupid*" [*Geranium x oxonianum*]).

There were also significant differences in the current popularity of species measured in the number of nurseries selling them with regard to the way they had been brought into the garden (Kruskal-Wallis chi-squared = 22.86, df = 5, p-value = 0.0004), again, also if the category "was already in the garden" was excluded (Kruskal-Wallis chi-squared = 17.02, df = 4, p-value = 0.0019). Plant species that had spread into the garden, were already in the garden or were given to respondents by other gardeners were sold by fewer nurseries than plant species they had bought themselves (Table 2). On average, species were offered by 21 nurseries.

Respondents also reported how the plants spread within their gardens. This was mainly through seeds (84 records), but also by roots (53), runners (40) and bulbs (21), in some cases by several means.

For the majority of reported plants (95) respondents undertook control with the aim to keep them confined in certain areas of their gardens, while in 47 cases they tried everything to get rid of them. For just nine and seven plants, respectively, they tolerated the plants or did not think they were a problem yet. There is no difference in control effort in relation to plants that were already in the gardens compared to plants gardeners had introduced themselves (Chisquare X-squared = 0.93, df = 2, p-value = 0.63), with 19 plants in both groups they wanted to get rid of.

The most common control methods employed were digging (123) and pulling (117), whereas chemical methods were only applied in 18 cases. For about half of the plants reported respondents used just one control method (84) but frequently they used two (62) or more (28). Additional control methods reported include removing of flower

and seed heads (8), digging up and sieving soil to sort out root fragments (2) and "*crying and cursing*" (*Anemone scabiosa*). The most popular methods for the disposal of removed plants was household green waste collection (85) followed by home composting (75) and household general waste collection (11). Respondents also mentioned burning (10), potting up "*for controlled redistribution*" (*Anemone scabiosa, Melissa officinalis*), putting plants in water to rot (*Pentaglottis sempervirens*), and feeding to goats (*Centranthus ruber*).

Most participants' gardens were bigger than the average garden size of 190 sqm in Britain (Davies et al. 2009) and located more frequently in older residential areas. Respondents estimating higher numbers for the total number of ornamental plant species in their garden did also buy more plant species in the year preceding the survey and reported more species as problematic from their gardens (Table 3). These differences are significant both for the number of species bought (Kruskal-Wallis chi-squared = 10.017, df = 4, p-value = 0.04015) and the number of species reported (Kruskal-Wallis chi-squared = 16.307, df = 4, p-value = 0.002633). The main points of purchase for new species were nurseries and garden centres, followed by plants received from friends and neighbours, through plant/seed swaps, and internet trade (Table 4).

Discussion

Our survey demonstrates that reports by the public are useful to identify potential invasive garden plants. The results show that the most frequent plants reported are also frequently recorded outside cultivation. Moreover, the list of reported plants also includes species with a recently increasing distribution and species not reported outside cultivation. While it could be argued confirming species already reported outside gardens would not be worth the effort of a citizen science project, the reports

of less frequent or not-recorded plants demonstrates that the approach is indeed useful to identify potentially invasive plants early on in the invasion process.

Only one of the species reported in our survey, *Crocosmia x crocosmiiflora,* is also among the just six alien species found in more than half of the 61 gardens analysed in a study of the flora of urban gardens in Sheffield, UK (Smith et al. 2006). However, the average number of 21 nurseries selling the species reported in our survey suggests that the species reported are popular garden plants. In particular, this number is very close to the average of 20 nurseries selling non-native species which are classified as established in the British flora compared to the average of eight nurseries selling species with just casual occurrences outside gardens as found in a random sample of 534 non-native ornamental plants (Dehnen-Schmutz et al. 2007b).

The main obstacle for the expansion of the approach to the wider gardening public is the potential difficulty with plant identification and motivation of participants. Our study mainly targeted members of the Botanical Society for Britain and Ireland (BSBI) who are likely to have better taxonomic knowledge than average gardeners, underlined by the fact that most of our respondents had submitted scientific names for plants and reported high confidence in their ability to have used the right identification. However, if less confident gardeners would participate these obstacles could be overcome for example if participants would have the opportunity to submit photographs of plants either centrally or by working in satellite networks with volunteer expert leaders to provide advice (Gallo and Waitt 2011). The second problem was the recruiting of participants for the survey. Even though the survey link was widely distributed (for example through the BSBI's twitter account with more than 10,000 followers), only 56 people took part. A more permanent reporting system rather than a short-term survey as used in this study could contribute to higher

numbers of respondents and the reporting system could be promoted on a regular basis as well as when opportunities arise (for example newspaper reports about problematic invasive plants). For an extended project and subsequent individual analysis of reported species it will also be important to consider other factors such as the climatic conditions in the locations from where the plants were reported. Despite these obstacles, the collaboration with gardeners also presents an excellent opportunity to establish a partnership for the prevention of ornamental plant invasions. The importance of involving stakeholders in the management of ornamental plant invasions is now widely acknowledged (Humair et al. 2014; Touza et al. 2014; Novoa et al. 2016; Hulme et al. 2018) but on the horticultural side it is often focused on wholesalers and nurseries. Policies aimed at gardeners in the role of consumers are mainly codes of conducts or labelling systems for plants (Verbrugge et al. 2014). By observing and reporting plants in their own gardens gardeners take to some extent ownership of the potential risk of invasions. Their willingness to report plants, and their own struggles in controlling them in their gardens also illustrates the potential support for labelling systems warning of these problems before purchase. Respondents still value the majority of the plants they reported with control efforts directed to confine them, but they also aim to get rid of a great number of plants totally. We found that plants recorded more widely outside gardens were less frequently available in the plant trade or not available to purchase at all. This could be for a number of reasons, including changing gardening fashions, increased non-commercial exchange (e.g. between neighbours) of species easy to propagate, decreasing supply as nurseries may decide not to sell plants that may cause their customers problems, or less of a demand from consumers for the same reasons. If gardeners could be made aware earlier, for example through labelling, as soon as

potential problems are recognised in gardens this could contribute to also greater awareness in disposing of plants and less frequent planting reducing propagule pressure.

Focusing risk managers' attention on plants that are showing first signs of potential invasiveness in gardens contributes to identify those that may need to be assessed in more detail. Given the high number of cultivated alien ornamental plants resources and efforts need to be prioritised; the approach used here could support this process. Plants reported but not known from outside cultivation could undergo a prioritisation process for risk assessment for example as specified by Branquart et al. (2016) for the EU; while similarly, for not yet widespread species, reports from gardens could provide additional evidence in such prioritisations. As a result, preventive measures could be initiated earlier. An online system for gardeners to report problematic ornamentals would ideally be maintained at a national authority level to guarantee consistent availability. Even with low submission numbers all evidence collected would be very valuable in official risk management procedures as well as supporting legal obligations on early detection, surveillance and monitoring.

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References

Adriaens T, Sutton-Croft M, Owen K, Brosens D, van Valkenburg J, Kilbey D, Groom Q, Ehmig C, Thürkow F, van Hende P, Schneider K (2015) Trying to engage the crowd in recording invasive alien species in Europe: experiences from two smartphone applications in northwest Europe. Management of Biological Invasions 6:215-225. http://doi.org/10.3391/mbi.2015.6.2.12

Armitage J, Edwards D, Konyves K, Lancaster N, Marshall R, Cubey J, Merrick J (2016) RHS plant finder 2016. Royal Horticultural Society, Wisley

Bradley BA, Blumenthal DM, Early R, Grosholz ED, Lawler JJ, Miller LP, Sorte CJB, D'Antonio CM, Diez JM, Dukes JS, Ibanez I, Olden JD (2011) Global change, global trade, and the next wave of plant invasions. Frontiers in Ecology and the Environment 10:20-28. http://doi.org/10.1890/110145

Branquart E, Brundu G, Buholzer S, Chapman D, Ehret P, Fried G, Starfinger U, van Valkenburg J, Tanner R (2016) A prioritization process for invasive alien plant species incorporating the requirements of EU Regulation no. 1143/2014. EPPO Bulletin 46:603-617. http://doi.org/10.1111/epp.12336

Cardoso AC, Tsiamis K, Gervasini E, Schade S, Taucer F, Adriaens T, Copas K, Flevaris S, Galiay P, Jennings E, Josefsson M, López BC, Magan J, Marchante E, Montani E, Roy H, von Schomberg R, See L, Quintas M (2017) Citizen Science and Open Data: a model for Invasive Alien Species in Europe. Research Ideas and Outcomes 3:e14811.

Davies ZG, Fuller RA, Loram A, Irvine KN, Sims V, Gaston KJ (2009) A national scale inventory of resource provision for biodiversity within domestic gardens. Biol Conserv 142:761-771. http://doi.org/10.1016/j.biocon.2008.12.016

Dehnen-Schmutz K (2011) Determining non-invasiveness in ornamental plants to build green lists. J Appl Ecol 48:1374-1380. http://doi.org/10.1111/j.1365-2664.2011.02061.x

Dehnen-Schmutz K, Touza J, Perrings C, Williamson M (2007a) A century of the ornamental plant trade and its impact on invasion success. Divers Distrib 13:527-534. **https://doi.org/10.1111/j.1472-4642.2007.00359.x**

Dehnen-Schmutz K, Touza J, Perrings C, Williamson M (2007b) The horticultural trade and ornamental plant invasions in Britain. Conserv Biol 21:224-231. **https://doi.org/10.1111/j.1523-1739.2006.00538.x**

Dullinger I, Wessely J, Bossdorf O, Dawson W, Essl F, Gattringer A, Klonner G, Kreft H, Kuttner M, Moser D, Pergl J, Pyšek P, Thuiller W, van Kleunen M, Weigelt P, Winter M, Dullinger S (2017) Climate change will increase the naturalization risk from garden plants in Europe. Glob Ecol Biogeogr 26:43-53. http://doi.org/10.1111/geb.12512

Early R, Bradley BA, Dukes JS, Lawler JJ, Olden JD, Blumenthal DM, Gonzalez P, Grosholz ED, Ibañez I, Miller LP, Sorte CJB, Tatem AJ (2016) Global threats from invasive alien species in the twenty-first century and national response capacities. Nature Communications 7:12485. http://doi.org/10.1038/ncomms12485

Essl F, Dullinger S, Rabitsch W, Hulme PE, Hülber K, Jarošík V, Kleinbauer I, Krausmann F, Kühn I, Nentwig W, Vilà M, Genovesi P, Gherardi F, Desprez-Loustau M-L, Roques A, Pyšek P (2011) Socioeconomic legacy yields an invasion debt. Proceedings of the National Academy of Sciences 108:203-207.

Faulkner KT, Robertson MP, Rouget M, Wilson JRU (2016) Understanding and managing the introduction pathways of alien taxa: South Africa as a case study. Biol Inv 18:73-87. http://doi.org/10.1007/s10530-015-0990-4

Foster G, Bennett J, Sparks T (2017) An assessment of bumblebee (Bombus spp) land use and floral preference in UK gardens and allotments cultivated for food. Urban Ecosystems 20:425-434. http://doi.org/10.1007/s11252-016-0604-7

Gallo T, Waitt D (2011) Creating a Successful Citizen Science Model to Detect and Report Invasive Species. Bioscience 61:459-465. http://doi.org/10.1525/bio.2011.61.6.8

Hulme PE, Bacher S, Kenis M, Klotz S, Kühn I, Minchin D, Nentwig W, Olenin S, Panov V, Pergl J, Pyšek P, Roques A, Sol D, Solarz W, Vila M (2008) Grasping at the routes of biological invasions: a framework for integrating pathways into policy. J Appl Ecol 45:403-414.

Hulme PE, Brundu G, Carboni M, Dehnen-Schmutz K, Dullinger S, Early R, Essl F, González-Moreno P, Groom QJ, Kueffer C, Kühn I, Maurel N, Novoa A, Pergl J, Pyšek P, Seebens H, Tanner R, Touza JM, van Kleunen M, Verbrugge LNH (2018) Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. J Appl Ecol 55:92–98. http://doi.org/10.1111/1365-2664.12953

Humair F, Siegrist M, Kueffer C (2014) Working with the horticultural industry to limit invasion risks: the Swiss experience. EPPO Bulletin 44:232-238. http://doi.org/10.1111/epp.12113

Kowarik I (2005) Urban ornamentals escaped from cultivation. In: Gressel J (ed) Crop ferality and volunteerism. CRC Press, Boca Raton, pp. 97-121

Lockwood JL, Cassey P, Blackburn T (2005) The role of propagule pressure in explaining species invasions. Trends Ecol Evol 20:223-228.

Mack RN (2000) Cultivation fosters plant naturalization by reducing environmental stochasticity. Biol Inv 2:111-122.

Novoa A, Kaplan H, Wilson JRU, Richardson DM (2016) Resolving a Prickly Situation: Involving Stakeholders in Invasive Cactus Management in South Africa. Environ Manag 57:998-1008. http://doi.org/10.1007/s00267-015-0645-3

Pergl J, Sádlo J, Petřík P, Danihelka J, Chrtek Jr. J, Hejda M, Moravcová L, Perglová I, Štajerová K, Pyšek P (2016) Dark side of the fence: ornamental plants as a source of wild-growing flora in the Czech Republic. Preslia 88:163-184.

Preston CD, Pearman DA, Dines TD (2002) New Atlas of the British and Irish Flora. Oxford University Press, Oxford

Pyšek P, Pergl J, Essl F, Lenzner B, Dawson W, Kreft H, Weigelt P, Winter M, Kartesz J, Nishino M, Antonova LA, Barcelona JF, Cabezas FJ, Cardenas D, Cardenas-Toro J, Castano N, Chacon E, Chatelain C, Dullinger S, Ebel AL, Figueiredo E, Fuentes N, Genovesi P, Groom QJ, Henderson L, Inderijt, Kupriyanov A, Masciadri S, Maurel N, Meerman J, Morozova O, Moser D, Nickrent D, Nowak PM, Pagad S, Patzelt A, Pelser PB, Seebens H, Shu W-s, Thomas J, Velayos M, Weber E, Wieringa JJ, Baptiste MP, van Kleunen M (2017) Naturalized alien flora of the world: species diversity, taxonomic and phylogenetic patterns, geographic distribution and global hotspots of plant invasion. Preslia. 89:203-274. http://doi.org/10.23855/preslia.2017.203

Pyšek P, Richardson DM (2007) Traits associated with invasiveness in alien plants: where do we stand? In: Nentwig W (ed) Biol Inv. Springer, Berlin, pp. 97-125

R Core Team (2015) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Roy HE, Rorke SL, Beckmann B, Booy O, Botham MS, Brown PMJ, Harrower C, Noble D, Sewell J, Walker K (2015) The contribution of volunteer recorders to our understanding of biological invasions. Biol J Linn Soc 115:678-689. http://doi.org/10.1111/bij.12518

Saul W-C, Roy HE, Booy O, Carnevali L, Chen H-J, Genovesi P, Harrower CA, Hulme PE, Pagad S, Pergl J, Jeschke JM (2017) Assessing patterns in introduction pathways of alien species by linking major invasion data bases. J Appl Ecol 54:657-669. http://doi.org/10.1111/1365-2664.12819

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jäger H, Kartesz J, Kenis M, Kreft H, Kühn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, van Kleunen M, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. 8:14435. http://doi.org/10.1038/ncomms14435

Smith RM, Thompson K, Hodgson JG, Warren PH, Gaston KJ (2006) Urban domestic gardens (IX): Composition and richness of the vascular plant flora, and implications for native biodiversity. Biol Conserv 129:312-322.

Stace CA, Crawley MJ (2015) Alien plants. Harper Collins, London
Touza J, Pérez-Alonso A, Chas-Amil ML, Dehnen-Schmutz K (2014) Explaining the rank order of invasive plants by stakeholder groups. Ecol Econom 105:330-341. http://dx.doi.org/10.1016/j.ecolecon.2014.06.019

van Kleunen M, Dawson W, Essl F, Pergl J, Winter M, Weber E, Kreft H, Weigelt P, Kartesz J, Nishino M, Antonova LA, Barcelona JF, Cabezas FJ, Cardenas D, Cardenas-Toro J, Castano N, Chacon E, Chatelain C, Ebel AL, Figueiredo E, Fuentes N, Groom QJ, Henderson L, Inderjit, Kupriyanov A, Masciadri S, Meerman J, Morozova O, Moser D, Nickrent DL, Patzelt A, Pelser PB, Baptiste MP, Poopath M, Schulze M, Seebens H, Shu W-s, Thomas J, Velayos M, Wieringa JJ, Pyšek P (2015) Global exchange and accumulation of non-native plants. Nature 525:100-103. http://doi.org/10.1038/nature14910

van Kleunen M, Essl F, Pergl J, Brundu G, Carboni M, Dullinger S, Early R, González-Moreno P, Groom QJ, Hulme PE, Kueffer C, Kühn I, Máguas C, Maurel N, Novoa A, Parepa M, Pyšek P, Seebens H, Tanner R, Touza J, Verbrugge L, Weber E, Dawson W, Kreft H, Weigelt P, Winter M, Klonner G, Talluto MV, Dehnen-Schmutz K (2018) The changing role of ornamental horticulture in alien plant invasions. Biological Reviews. https://doi.org/10.1111/brv.12402

Verbrugge LNH, Leuven RSEW, van Valkenburg JLCH, van den Born RJG (2014) Evaluating stakeholder awareness and involvement in risk prevention of aquatic invasive plant species by a national code of conduct. Aquatic Invasions 9:369-381. http://dx.doi.org/10.3391/ai.2014.9.3.11

Williamson M, Dehnen-Schmutz K, Kühn I, Hill M, Klotz S, Milbau A, Stout J, Pyšek P (2009) The distribution of range sizes of native and alien plants in four European countries and the effects of residence time. Divers Distrib 15:158-166. **https://doi.org/10.1111/j.1472-4642.2008.00528.x**

Figure captions

Fig. 1: Pathways into gardens of plant species reported and the frequency of records outside gardens in Britain (“frequent” >100 hectads, “present” <=100 hectads and “not-outside” (no records outside gardens). Species can be included more than once if introduced through different pathways into different gardens.

Fig.1

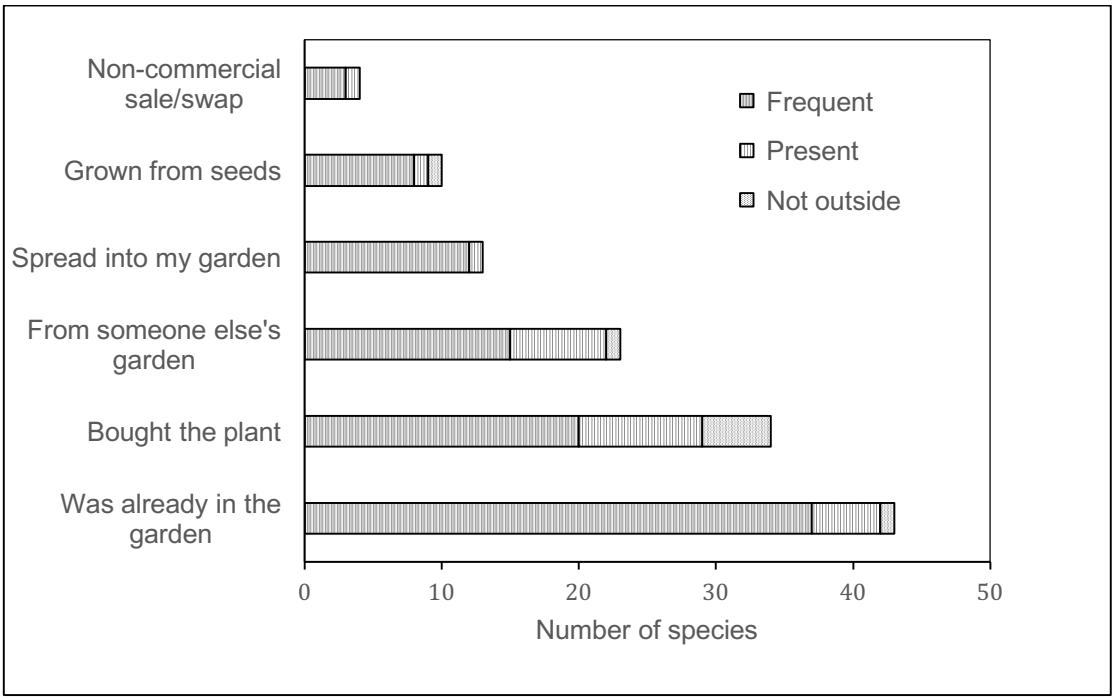
Non-commercial sale/swap
Grown from seeds
Spread into my garden
From someone else's garden
Bought the plant
Was already in the garden
Frequent
Present
Not outside
0
10
20
30
40
50
Number of species

Table 1: Species reported with no known occurrences outside gardens in Britain at the time of the study. Information on naturalisation outside their native range was taken from the GloNAF database (van Kleunen et al. 2015; Pyšek et al. 2017)

Species	Family	Origin	Naturalised (Continent*)
Anemone sylvestris	Ranunculaceae	Europe	Yes (Eu)
Arctotheca prostrata	Asteraceae	S. Africa	Yes (Af, AsTm, Au, AmN)
Asclepias speciosa	Apocynaceae	N. America	Yes (AmN)
Carex trifida	Cyperaceae	New Zealand	No
Geranium cinereum	Geraniaceae	Europe	No
Libertia peregrinans	Iridaceae	New Zealand	No
Moraea huttonii	Iridaceae	S. Africa	No
Tetrapanax papyrifer	Araliaceae	Asia	Yes (Af, AsTm, AsTr, AmN, AmS, Au, P

*Af = Africa, AsTm = Asia (temperate), AsTr = Asia (tropical), AmN = North America, AmS = South America, Au = Australasia, Pa = Pacific Islands, Eu = Europe

Table 2: Availability of plant species reported in the survey in the horticultural trade as measured by number of nurseries selling the species in the Plant Finder ((https://www.rhs.org.uk/Plants/Search-Form accessed June 2016). Some species are included in several categories. N gives the number of species for each category (including species reported more than once), mean and median are calculated at the species level for each category (excluding species reported twice).

Pathway into garden	N	Min	Max	Mean	Median	not in PF
Bought the plant	44	0	121	28.1	19.5	2
From someone else's garden	30	0	70	21.0	9.5	1
Grown from seeds	10	0	121	37.1	21.0	1
Non-commercial sale/swap	5	12	56	28.8	23.5	0
Spread into my garden	20	0	33	7.6	5.0	2
Was already in the garden	65	0	76	14.1	8.0	4
Unknown	3	4	8	6.3	7.0	0

Table 3: Estimated number of ornamental plant species in respondents' gardens (N = number of respondents), the mean number of new species they bought in the previous year (newpmean) and the mean number of species difficult to control they reported in the survey (repmean).

Plants in garden	N	newpmean	repmean
Less than 20	3	2.0	2.3
Between 20-50	18	7.4	2.9
Between 50-100	14	11.6	3.7
More than 100	19	29.3	4.3
I don't know/ impossible to estimate	2	9.0	4.5

Table 4: Points of purchase of new plants bought by respondents in the previous year. Multiple answers were possible.

Point of purchase	Respondents
Nursery	28
Garden centre	27
Friends/neighbours	17
Internet order	11
Plant/seed swap	11
Supermarket	8
Mail-order	8
Other	4