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Waterborne spread of introduced plants from a large ornamental garden in northern England, UK

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Abstract
The spread of non-native plants from ornamental gardens is an introduction pathway that has rarely been studied in detail. Here we document the escape of garden plants along a riparian corridor below a large ornamental garden in northern England. Of the 42 naturalised garden escapes found, 14 had originated from the garden itself including two species that were locally invasive (*Cardamine bulbifera*, *Lysichiton americanus*). Along with the ubiquitous *Impatiens glandulifera*, *C. bulbifera* was the most abundant non-native and had spread by bulbils to form dense stands on sandy riverbanks disturbed by winter floods whereas *L. americanus* had spread by seed to form dense stands in swampy woodland. All other non-natives were locally distributed. These findings highlight the important role that ornamental gardens play as 'entry points' for non-native plants and emphasises the need for gardens to identify, manage and in some cases eradicate potentially invasive species, especially where they have the potential to escape and spread along watercourses.

Keywords: garden escapes; hydrochory; introductions; invasive; naturalised; watercourses.

Introduction

'Garden escapes' are plants that spread from ornamental collections into the surrounding landscape via natural dispersal of seeds and vegetative propagules by wind, water, birds and animals (Stace & Crawley, 2015). These are usually plants that have been imported to the country for ornamental use but can also include species that are native in the region but are frequently grown in gardens or have garden varieties that frequently escape to into the habitats where they can grow alongside native populations (e.g. *Lamiastrum galeobdolon* subsp. *argentatum* in British woodlands). Humans are also an important vector transporting propagules in soil or garden waste discarded in wild locations (i.e. garden throw-outs or outcasts). Often this garden waste includes propagules of plants that have become invasive in gardens and so many escapees often go on to reproduce in the wild (i.e. established, naturalised), in some cases altering the composition of semi-natural plant assemblages that they invade. One pathway that has received less attention is the dispersal of seeds and propagules from ornamental gardens by water

(hydrochory). This is surprising given that watercourses often provide 'highways' along which non-native plants can spread, circumventing natural barriers that would normally restrict their movement on land (e.g. urban or upland areas). In Britain, some of the most famous examples are *Heracleum mantegazzianum* and *Impatiens glandulifera* which both originated in large ornamental gardens in the 19th century and have since established over 1000s of kilometres alongside waterways throughout the whole of western Europe (Wadsworth *et al.*, 2000). Less well documented British examples include *Allium paradoxum* (Braithwaite, 2014), *Arenaria balearica* (Corner, 1996), *Erythranthe* species, *Hesperis matronalis*, *Impatiens capensis*, *Lathraea clandestina* (Atkinson, 1996), *Lysichiton americanus* (Sanderson, 2013), *Petasites japonicus* and *Tellima grandiflora*.

Ornamental and botanic gardens have long been recognised as serious 'entry points' for many non-native plants and globally this is now recognised as a serious issue for plant conservation (Hulme, 2011, 2014) leading to calls for individual gardens to implement strategies that identify and control potentially invasive species that occur within their grounds (Culley et al., 2022). Britain has been a global centre for plant collections since the building of Kew Gardens in Surrey in 1759 and since then ornamental gardens have been opened in many British cities. This has resulted in several widely publicised examples of plants 'jumping the garden wall', such as *Senecio squalidus* from Oxford Botanic Garden (Kent, 1956) and *Galinsoga parviflora* from Kew (Lacey, 1957). Despite their undoubted importance as 'entry points', there have been few studies documenting the spread of non-natives away from them; notable exceptions include Ronse (2011) who documented escapes from the Botanic Garden of Belgium and Zhang (1983) who described the spread of *Fritillaria meleagris* from the Uppsala botanic garden in the 19th century.

In this study, we document the waterborne spread of non-native plants along a riparian corridor below a large ornamental garden in northern England. We describe the composition, abundance, and habitats of this ornamental flora, their potential impacts on the native species and communities and implications for the management of non-native plants by ornamental gardens. Nomenclature for vascular plants follows Stace (2019).

Methods

Study area

This study focussed on watercourses downstream from the Royal Horticultural Society's (RHS) Harlow Carr Gardens on the western outskirts of Harrogate, North Yorkshire (Fig 1.). This ornamental garden was created in the 1940s on the site of a former hotel and spa that was originally mixed woodland, pasture and arable land, and, when opened in 1950 had the aim of assessing the suitability of plants for growing in northern climates. Since then, the site has been substantially developed as formal gardens and now covers 23 hectares (58 acres) with ornamental collections comprising many 1000s of species with a focus on cooler climates, especially mountain regions of central and eastern Asia and North America. The garden was acquired by the RHS in 2000 and receives over 400,000 visitors annually.

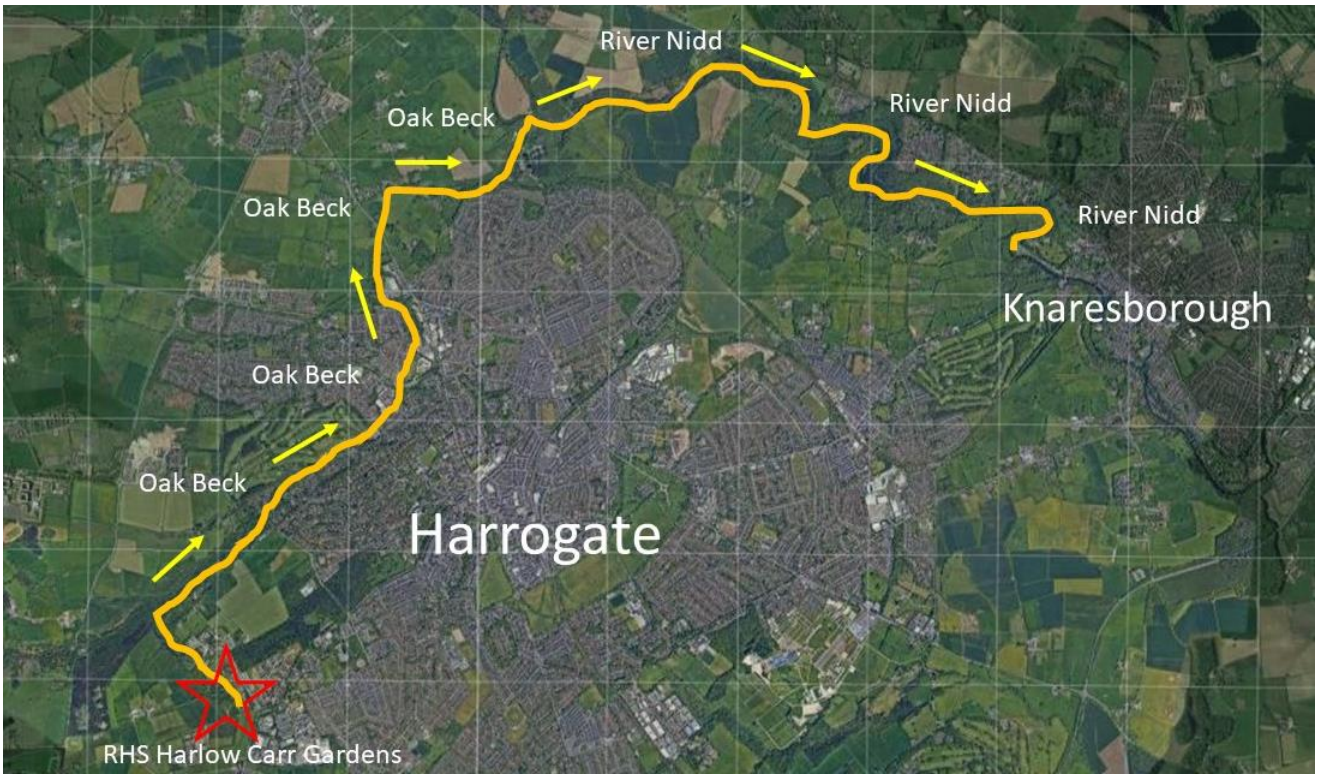

Figure 1. The watercourses downstream of RHS Harlow Carr included in this study.

One of the main features of the garden is a small fast-flowing stream that exits the garden on its northern boundary where it then joins the Oak Beck, a tributary of the River Nidd which it joins six kilometres downstream. These watercourses pass through deciduous woodland, pasture, suburban housing estates, and a large gorge between Harrogate and Knaresborough. The riverbanks mainly support deciduous woodland with *Acer pseudoplatanus*, *Alnus glutinosa*, *Betula pubescens*, *Fraxinus excelsior*, *Quercus robur* and *Ulmus glabra*. The ground flora is typical of oak and ash woodland on brown soils in northern England (W7/8 sensu Rodwell, 1991) with frequent *Aegopodium podagraria*, *Allium ursinum*, *Anemone nemorosa*, *Anthriscus sylvestris*, *Ficaria verna*, *Galium aparine*, *Hyacinthoides non-scripta*, *Geum urbanum*, *Luzula sylvatica*, *Mercurialis perennis*, *Oxalis acetosella*, *Rubus fruticosus* and *Urtica dioica* (Walker, 2009; 2017). There are also small pockets of wet woodland, with alder and willows, in low-lying depressions immediately adjacent to the watercourses supporting local specialities such as *Carex paniculata*, *Cardamine amara*, *Stellaria nemorum* and *Chrysosplenium alternifolium.*

Survey

The occurrence of established garden escapes was mapped along *c.*12 km of watercourses between RHS Harlow Carr and the western outskirts of Knaresborough (Fig. 1). Recording took place in late May and June and entailed a slow walk along riverbanks noting the occurrence of all introductions growing within the watercourse

itself, on the adjacent riverbank or within the riparian (flood) zone, including flushes and low-lying areas of wet woodland immediately adjacent to the watercourses. Except for two small sections, watercourses were accessible on at least one riverbank with both banks surveyed whenever possible. Garden escapes were recorded within 100 x 100 m grid squares (n=114) of the OS National Grid using a handheld GPS. Within each 100 m grid square the abundance of each non-native plant was estimated by eye using the 'AFOR' scale of abundance (Abundant, Frequent, Occasional, Rare).

Results

Garden escapes

Forty-two garden escapes were recorded as naturalised in the riparian zone in the study area (Table 1), including four species that are native to Britain but in the study region occur as garden escapes (*Cardamine bulbifera*, *Daphne laureola*, *Hypericum androsaemum*, *Papaver cambricum*). Of these, 14 were known or strongly suspected to have originated from RHS Harlow Gardens on the basis that they are known to occur in the garden but are absent or very uncommon in the region as a whole (Table 1). The two exceptions were *Doronicum pardialanches* and *Tellima grandiflora*, both of which are equally widespread outside of the study area, but which were strongly suspected as having originated from the botanic garden given their distribution locally.

Table 1. The habitats, frequency and abundance of garden escapes originating from RHS Harlow Carr Gardens. '% 100m' is the % of the 114 100 x 100 m grid cells in which the species was recorded and '% 1km' is the % of 1 x 1 km grid squares (monads) in which the species has been recorded in the study area expressed as a proportion of the monads in the Harrogate recording area. 'Abundance' is the mean AFOR score across all the 100m grid in this study (abundant = 4; frequent = 3; occasional = 2; rare = 1). 'x' indicates presence.

Species	Riverbank	Stream	Wood	% 100m	% 1km	AFOR
Cardamine bulbifera	x		x	83	70	2.1
Tellima grandiflora	x			39	46	1.5
Lysichiton americanus		x	x	29	83	1.7
Ranunculus aconitifolius		x		16	86	1.3
Cardamine raphanifolia	x			15	83	1.3
Doronicum pardalianches	x			9	33	1.2
Pachyphragma macrophyllum	x			4	100	1
Lathraea clandestina	x		x	3	57	1.7
Symphytum x *hidcotense*	x			3	75	1.3
Lysichiton camtschatcensis		x	x	2	100	1
Petasites japonicus	x			2	50	1
Trachystemon orientalis	x			2	67	1.5
Anemone ranunculoides	x			1	50	1
Sasa palmata	x			1	100	1

By far the most frequent escape from RHS Harlow Carr was the nationally native but locally introduced *Cardamine bulbifera* which, along with *Impatiens glandulifera*, was found to be the most widespread non-native plant in the study area occurring in 83% of the 100 m grid squares (Fig. 2A). Other frequent escapes included *Tellima grandiflora* (39%; Fig. 2B), *Lysichiton americanus* (29%; Fig. 2C), and *Ranunculus aconitifolius* (16%; Fig. 2D). Much more localised were *Cardamine raphanifolia* (15%), *Doronicum pardialanches* (9%), *Lathraea clandestina* (3%), *Lysichiton camtschatcensis* (2%), *Pachyphragma macrophyllum* (4%), *Petasites japonicus* (2%), *Symphytum* x *hidcotense* (3%), and *Trachystemon orientalis* (2%). In comparison, *Anemone ranunculoides* and *Sasa palmata* were only recorded by the stream adjacent to the rear of the garden in an area where garden waste had been discarded in the past.

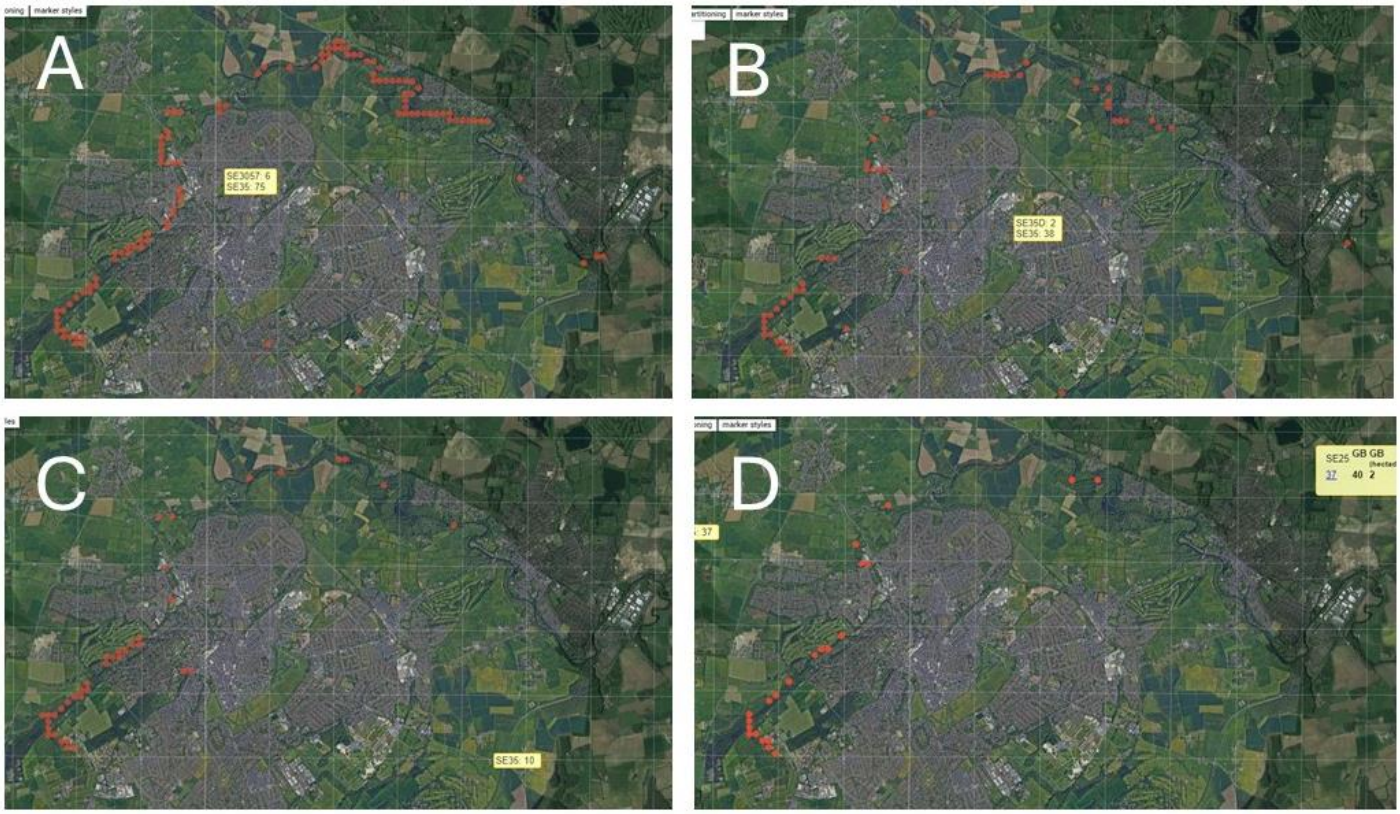

Figure 2. The distribution of ornamental plants that have escaped from RHS Harlow Carr Gardens and spread along watercourses near to Harrogate, North Yorkshire: (a) *Cardamine bulbifera*, (b) *Tellima grandiflora*, and (c) *Lysichiton americanus*, and (d) *Ranunculus aconitifolius*.

The remaining 28 garden escapes are so widely distributed in the region that their origins are now obscure (Table 2). By far the most widespread was *Impatiens glandulifera* (83%) which is now virtually ubiquitous along watercourses in the region often forming very dense stands. Likewise, *Claytonia sibirica* (47%), *Hesperis matronalis* (27%), *Tolmiea menziesii* (24%), *Hypericum androsaemum* (17%), and *Narcissus* sp. (13%) are all frequent garden escapes in the Harrogate area. The remaining 22 species were more localised with just a handful of locations and

included common garden escapes such as *Galanthus nivalis*, *Hyacinthoides* x *massartiana*, *Lamiastrium galeobdolon* susbp. *argentatum*, and *Papaver cambricum*.

Table 2. The habitats, frequency and abundance garden escapes below RHS Harlow Carr Gardens that probably originated from domestic gardens in the study area. '% 100m' is the % of the 114 100 x 100 m grid cells in which the species was recorded and '% 1km' is the % of 1 x 1 km grid squares (monads) in which the species has been recorded in the study area expressed as a proportion of the monads in the Harrogate area. 'Abundance' is the mean AFOR score across all the 100m grid in this study (abundant = 4; frequent = 3; occasional = 2; rare = 1). 'x' indicates presence.

Species	Riverbank	Stream	Wood	% 100m	% 1km	AFOR
Impatiens glandulifera	x		x	83	6	2.5
Claytonia sibirica	x		x	47	21	1.7
Hesperis matronalis	x			27	10	1.5
Tolmiea menziesii	x		x	24	33	1.5
Hypericum androsaemum agg.**	x			17	23	1.1
Narcissus sp.	x			13	9	1
Hyacinthoides x *massartiana*	x			6	18	1.1
Symphoricarpos albus			x	6	10	1
Galanthus nivalis	x			4	6	1
Arum italicum	x			3	33	1.3
Lamiastrum galeobdolon subsp. *argentatum*	x			3	22	2
Centaurea montana	x			2	7	1
*Daphne laureola**			x	2	13	1
Erythranthe sp.		x		2	13	1
*Papaver cambricum**	x			2	11	1
Petasites pyrenaicus	x			2	22	2.5
Pulmonaria officinalis	x			2	18	1
Ribes sanguineum	x			2	20	1
Allium paradoxum	x			1	5	1
Crocosmia x *crocosmiiflora*	x			1	11	1
Forsythia suspensa	x			1	0	1
Hedera colchica	x			1	43	2
Helleborus sp.	x			1	13	1
Koenigia campanulata	x			1	100	1
Leucanthemum x *superbum*	x			1	8	1
Lysimachia punctata	x			1	0	2
Muscari armeniacum	x			1	8	1
Polygonatum x *hybridum*	x			1	17	1

*Native species in Britain but introduced in the study area.
**Many records are likely to refer to the garden hybrid *H. x inodorum*.

Ecology of the main escapes

In this study, the most widespread garden escape was *Cardamine bulbifera* which as a native is restricted to woods on chalk and clay in southeast England but has increasingly been recorded as a garden escape in recent decades (Stroh *et al*., 2023). It appears to have been accidentally introduced to RHS Harlow Carr in the 1980s in compost used to transport lily bulbs from Essex (Manson, 2004). Since then, it has run wild in the garden borders despite several attempts to control it. It was first reported outside the garden in 1998 although it may have been present there for some time (Manson, 2004; Wallace, 2005) and its subsequent spread was documented by Walker (2009). In the present study its was by far the most abundant escape, often forming dense patches on sandy riverbanks disturbed by winter flooding (Fig. 3A) but rare in undisturbed riverbank vegetation dominated by *Allium ursinum*. It is a perennial herb that flowers in April and May and regeneration is mainly by bulbils which develop in the leaf axils and regenerate rapidly on bare sand or soil (Walker, 2009). Most bulbils either fall directly into the watercourse or are washed into it and dispersed to new locations during periods of high water-level typically in the winter months (Showler & Rich, 1993; Walker, 2009).

Figure 3. A selection of ornamentals originating from RHS Harlow Carr that are now naturalised by the Oak Beck, Harrogate: A) *Cardamine bulbifera*, B) *Lathraea clandestina*, C) *Lysichiton americanus* and D) *Pachyphragma macrophyllum*.

Tellima grandiflora and *Lysichiton americanus* are both North American perennial herbs of wetlands that regenerate readily by seed, and this presumably

accounts for their dramatic spread in Britian in recent decades (Stroh *et al*., 2023). In the study area both were found growing as single patches on bare soil and rock on the banks of watercourse and in wet woodland (alder-willow carr), the latter forming dense patches (Fig. 3C). *L. americanus* has been grown as a 'bog garden' plant at RHS Harlow Carr for many decades (Fig. 4) but following concerns raised over its spread along the Oak Beck the seedheads have been removed after flowering each year.

Figure 4. *Lysichiton americanus* growing in the 'bog garden' by the stream in the Royal Horticultural Society's Harlow Carr Gardens on the outskirts of Harrogate, UK. These plants are the source of the populations that are now well-established downstream along the Oak Beck and River Nidd.

Ranunculus aconitifolius, *Cardamine raphanifolia* and *Doronicum pardialanches* are all attractive perennial herbs of montane habitats in Europe that were much more localised occurring as singletons in the study area amongst rocks or on sandy soils on streamsides. All three are grown in rocky gardens and have spread, particularly in upland regions of northern and western Britain in recent decades (Stroh *et al*., 2023). In comparison, *Pachyphragma macrophyllum* from deciduous forests in the Caucasus and Pontic Alps, is only naturalised in a few locations in Britain including one site where it has persisted since at least 1964 (Davie & Akeroyd, 1983). It has been grown at RHS Harlow Carr for many decades and still occurs in a few shaded herbaceous borders. In the study area, about half a dozen patches were found on riverbanks amongst dense carpets of *Allium ursinum*

(Walker, 2017). Although it flowers throughout late March and April its ability to regenerate by seed appears limited (Rich, 1991) and so it is likely to have become established through the dispersal of tough rhizome fragments (Walker, 2017).

One of the most attractive garden escapes in the study area was *Lathraea clandestina*, a parasitic herb native to western Europe (Belgium, France, Spain, Italy) where it grows in wet woodland and spreads by seed, particularly along watercourses (Atkinson & Atkinson, 2020). In Britain it has been planted as a curiosity in large gardens from where it has occasionally spread (Atkinson, 1996). It is known to occur in the arboretum at RHS Harlow Carr from where it has spread to a handful of locations in the study area, mainly growing on the roots of large crack willows (*Salix fragilis*) in alder-willow carr and on riverbanks (Fig. 2B). Colonies were typically small although at the site shown in Fig. 2B there were *c.*65 patches with 1000s of flowers.

Discussion

The findings of this study show the extent to which large ornamental gardens can act as 'entry points' for exotic plants, especially when connected to the surrounding landscapes by watercourses. This allows plants that regenerate readily by seed or vegetative fragments to spread rapidly along riparian corridors and invade adjacent semi-natural habitats through dispersal by humans or animals. Well known examples in Europe that have spread in this way include *Impatiens glandulifera* and *Heracleum mantegazzianum.* The most widespread garden escape in this study was *Cardamine bulbifera* which appears to have spread rapidly due to the dispersal of bulbils that are produced in the leaf axils during the spring. Other alien plants that have spread in the same way in recent decades include *Ficaria verna* subsp. *bulbifer* and most notably *Allium paradoxum* which has spread along many riparian corridors in Northern England (Braithwaite, 2014) in some places threatening localised species that occur in the same habitat such as *Gagea lutea* (Walker, 2021).

Impacts

Three of the garden escapes recorded in the study area are likely to have had a significant impact on populations of native species in riparian habitats. *Impatiens glandulifera* and *Cardamine bulbifera* formed dense stands on sandy riverbanks disturbed by winter-floods and research on the former species in Europe suggest that this will have led to a decline in the abundance of smaller native species confined to open conditions, which in the study area include *Adoxa moschatellina* and *Chrysosplenium alterniflorum* (e.g. Hejda & Pysek, 2006; Hulme & Bremner, 2006; Coakley & Petti, 2021). No such research has been carried out on the impacts of *C. bulbifera* which is not surprising given its status as a much-loved native rarity in Britain but observations in the study area suggest that this species is highly likely to be reducing the abundance of native species in the same habitat.

In comparison, *Lysichiton* americanus, which is now banned from sale in the U.K., formed dense stands in very wet, boggy areas in wet woodland. Its attractive yellow flowers are produced in the spring but when in fruit the leaves enlarge reducing the physical space for other species and casting a deep shade. The impact of this species has not been studied in detail but surveys in the New Forest suggest that it is likely to be out-competing native associates (Sanderson, 2013) which in this

study included wetland plants such as *Caltha palustris*, *Cardamine amara, Chrysosplenium oppositifolium*, *C. alterniflorum* and *Veronica beccabunga*.

In this study, the only other garden escape that formed dense stands was *Tolmeia menziesii* which grows with its close relative *Tellima grandiflora* in North America (Weiblen & Brehm, 1996) and in Britian, but is potentially more invasive due to its ability to spread clonally to form dense patches in wet woodland and flushes.

Implications for ornamental gardens

The findings of this study highlight the need for ornamental gardens to be more proactive in how they deal with potentially invasive plants, especially where they have the potential to spread into surrounding landscapes along watercourses. We recommend three actions that could help to limit the spread of potentially invasive species and raise awareness of the risks they pose. First, horticulturalists who run ornamental gardens should avoid growing plants that are known to be invasive. Where these already occur (as in the case of *Lysichiton americanus* at RHS Harlow Carr), species displaying invasive tendencies should either be eradicated or managed to limit their spread. For example, staff at RHS Harlow Carr carefully remove the seedheads of *Lysichiton americanus* and *L. camtschatcensis* before they reach maturity each year. The removal of waste of such species also needs to be carefully managed to ensure that species do not establish from discarded seeds or vegetative fragments. There are now numerous resources to help identify such species in the UK through wider engagement initiatives such as PlantAlert and Be Plant Wise. Second, ornamental gardens can play an important role in identifying potentially invasive species by monitoring their behaviour within their own gardens. The behaviour of *Cardamine bulbifera* at RHS Harlow Carr is a good example. This was accidentally introduced but then became a troublesome weed within the garden before escaping. Such information could be shared with other ornamental gardens through established networks so that they are aware of species to avoid. Ideally, garden staff should also monitor the immediate surroundings, especially watercourses, to see whether species are escaping, or possibly contact local natural history groups to see if they can undertake surveys. Finally, ornamental gardens should help to raise awareness of the potential harm that some garden plants can cause if they escape into the wild. For example, RHS Harlow Carr has interpretation panels by the bog garden to help raise awareness of the potential risks it poses to native species (Fig. 4). More broadly, gardens also have a role to play in educating gardeners of the risks of discarding garden waste in semi-natural habitats where vigorous garden plants can go on to establish and cause problems for native species (e.g. *Hyacinthoides x massartiana*).

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