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Integrating invasive species policies across ornamental horticulture supply-chains to prevent plant invasions

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Summary

1. Ornamental horticulture is the primary pathway for invasive alien plant introductions. We critically appraise published evidence on the effectiveness of four policy instruments that tackle invasions along the horticulture supply-chain: pre-border import restrictions, post-border bans, industry codes of conduct, and consumer education.
2. Effective pre-border interventions rely on rigorous risk assessment and high industry compliance. Post-border sales bans become progressively less effective when alien species become widespread in a region.
3. A lack of independent performance evaluation and of public disclosure, limits the uptake and effectiveness of voluntary codes of conduct and discourages shifts in consumer preference away from invasive alien species.
4. *Policy implications.* Closing the plant invasion pathway associated with ornamental horticulture requires government-industry agreements to fund effective pre- and post-border weed-risk assessments that can be subsequently supported by widely adopted, as well as verifiable, industry codes of conduct. This will ensure producers and consumers make informed choices in the face of better targeted public education addressing plant invasions.

Keywords: biological invasions, biosecurity, exotic, gardening, invasive species, nurseries, legislation, non-native, trade, weed

Introduction

The global trade in ornamental nursery stock is the dominant pathway by which invasive alien plants have been introduced worldwide (Lambdon *et al.* 2008; Jiang *et al.* 2011; Lehan *et al.* 2013; Dodd *et al.* 2015; Rojas-Sandoval & Acevedo-Rodriguez 2015; Faulkner *et al.* 2016). This is not surprising since the ornamental nursery trade (comprising commerce in finished, bareroot and seedling trees, shrubs, ground covers, grasses, vines and aquatic plants of sale size, bulbs and seeds) is largely built around commerce in alien plant species, their hybrids, cultivars and varieties (Drew, Anderson & Andow 2010). Alien species often represent a higher proportion than native species in terms of what is cultivated, the available stock in retail outlets and consumer purchases. For example, in both Great Britain and New Zealand, there is an order of magnitude greater number of plant species in cultivation than native plant species in the wild (Gaddum 1999; Armitage *et al.* 2016). In the USA, alien species comprise as much as 80% of the stock held by nurseries (Brzuszek & Harkess 2009; Harris *et al.* 2009) and account for up to 90% of nursery revenue (Kauth & Perez 2011). While only a relatively small proportion of taxa escape cultivation, often less than 10% (Hulme 2012), the sheer number of taxa cultivated results in the ornamental pathway being the main source of naturalised and invasive alien plant species in natural areas worldwide (Fig. 1).

Annual sales of nursery stock amount to US$430 million in Canada (Agriculture-Canada 2015), US$500 million in Australia (PHA 2015), US$1,054 million in the United Kingdom (Defra 2016) and US$4,267 million in the USA (USDA 2014). Policymakers could therefore argue that plant invasions are an unavoidable minor cost incurred to support an industry that delivers significant economic benefits and brings pleasure to millions of gardeners. But can appropriate policies be designed to target the ornamental nursery industry supply-chain such that changes to operations to mitigate invasions will be most easy to implement, cost-effective and acceptable?

Integrating invasive species policy across the ornamental plant supply-chain

The ornamental nursery supply-chain involves many different actors whose roles vary depending on the types of plants sold and the relative importance of national and international markets for their products (Kaim & Mueller 2009; Drew, Anderson & Andow 2010). While no two supply-chains will be the same, most include the following actors: importers of new and existing germplasm; plant breeders and propagation nurseries; growers and plant production nurseries; wholesale suppliers; landscape-industry trade outlets; public retail outlets (specialist nurseries, garden centres, hardware stores etc.); and finally a wide range of public, business and government consumers (Fig. 2). Vertical integration in the industry results in organisations playing multiple roles in the supply-chain. For example, botanic gardens not only import new germplasm but they are often also involved in plant breeding as well as retail to the general public (Hulme 2011).

Actors within the ornamental nursery industry have different motivations, knowledge of invasive plant species and enthusiasm for market change (Humair, Kueffer & Siegrist 2014). Thus while several policies exist addressing plant invasions arising from ornamental horticulture (Reichard & White 2001; Barbier *et al.* 2013), they have seldom been viewed as an integrated suite of options targeting different actors (Drew, Anderson & Andow 2010). Preventing the introduction or establishment of potentially invasive alien species is often the most cost-effective and environmentally desirable policy option to manage invasions (Keller, Lodge & Finnoff 2007). The ornamental industry supply-chain can be used to assess the merit of four major policy instruments targeting prevention: pre-border import restrictions; post-border plant sales bans (both affecting breeders, propagators and producers); industry codes of conduct (adopted by trade and public retail outlets); and tools to engender consumer behavioural change through increased public awareness.

Pre-border restrictions on the import of invasive plants

Two contrasting approaches have been developed to restrict the importation of invasive alien plant species: blacklists that treat all unlisted plant imports as innocent until proven guilty versus whitelists that view all unlisted plants as guilty until proven innocent (Dehnen-Schmutz 2011). Both New Zealand and Australia have adopted a stringent whitelist approach in which species not recorded on a permitted list require evaluation through a formal weed-risk assessment procedure (Auld 2012). European nations often promote blacklists as a cost-effective means to limit the importation of invasive alien plants (Essl *et al.* 2011). Under these circumstances weed-risk assessments are used to support the listing of species on blacklists. However, due to the large number of ornamental species available for import, cost of risk assessments, and the frequent lack of consensus among stakeholders in relation to the listing criteria, blacklists are rarely comprehensive and are generally less effective than a whitelist of permitted species (Hulme 2015a).

Furthermore, without mechanisms to check compliance, particularly in the face of increasing internet trade in invasive alien species (Humair *et al.* 2015) and poor species identification (Thum, Mercer & Wcisel 2012), both blacklists and whitelists can be easily bypassed. Whereas in New Zealand all incoming travellers, shipping containers and mail items are screened for potential risk goods, this is not the case in most other countries where national borders are more porous and the biosecurity infrastructure less effective. As a consequence, legislation often has to be updated retrospectively following the discovery that a previously introduced species has become invasive in the territory. Under these circumstances, policy considerations shift from prohibiting entry towards preventing the wider dissemination and spread of species already in cultivation.

Post-border banning of invasive plant species from sale

Following invasion by an ornamental plant species, one option for policymakers is to legislate a ban on the sale of nursery stock, seeds or other propagating material and place restrictions on its movement. Sales bans are generally based on formal risk assessment procedures similar to those used pre-border and are usually only put in place after a period of consultation with the ornamental plant industry. However, industry opposition to sales bans can be strong and often results in species being dropped from legislation. For example, in relation to a ban on the sale of five aquatic ornamental plants in Great Britain in 2013, the Ornamental Aquatic Trade Association (OATA) ensured three species worth over US$4million in annual sales were not listed and “campaigned long and hard to make the proposed prohibition list as short as possible” (OATA 2013). While surveys often reveal the ornamental nursery industry supports existing sales bans (Coats, Stack & Rumpho 2011; Vanderhoeven *et al.* 2011; Humair, Kueffer & Siegrist 2014; Verbrugge *et al.* 2014), such assessments may underestimate the intense industry opposition and lobbying prior to any sales ban being implemented. In the future, it would be valuable for surveys of industry attitudes to new regulation to be undertaken before any agreement with government has been reached in order to better capture motivations and concerns of horticultural professionals. In addition, if mechanisms to enforce regulations are weak then compliance with legislation is often poor. An assessment of over 1000 ornamental nurseries in the USA indicated rates of compliance with invasive species regulations to be less than 50% (Oele *et al.* 2015).

Sales bans can also be ineffective in limiting the negative impact of plant invasions if the target species is already widespread in the region. The consultation on banning plants from sale in Great Britain initially targeted 15 species, however, several of these were already so widespread that the logic of any sales ban impacting on their future spread was challenged by the ornamental industry and these species were not listed (Fig. 3). Even for the five species that were subsequently banned from sale, the legislation will have greatest impact on the two least common species: floating pennywort *Hydrocotyle ranunculoides* and water primrose *Ludwigia grandiflora*. For the remaining three species, a sales ban may be insufficient to prevent further spread and thus, to be most effective, the legislation would need to be supported by a coordinated eradication campaign. Even under this ideal scenario, escapes will continue to occur through natural dispersal and illegal dumping of green waste from existing plantings in public and private gardens.

Codes of conduct and industry self-regulation

Increasing governmental support for deregulation combined with industry opposition to restrictive legislation has led to a progressive emphasis on corporate responsibility and voluntary codes of conduct worldwide (Sethi 2011). Several voluntary codes of conduct have been developed to address the management of invasive plant species by the ornamental nursery industry (Baskin 2002; Heywood & Brunel 2009; Verbrugge *et al.* 2014). These voluntary codes of conduct suffer from a number of drawbacks that limit their contribution to preventing the import, propagation and sale of invasive plants.

An important aspect of any voluntary code of conduct is that there should be consequences for non-compliance in terms of bad publicity and brand image. This requires that suppliers and customers can readily identify actors participating in voluntary codes of conduct and would involve procedures to audit compliance reasonably frequently. Therefore, while it is crucial to monitor and evaluate the performance of codes of conduct, and to ensure public disclosure, these actions have never been included in voluntary codes of conduct for the ornamental nursery industry. As there are no means of assessing how well the codes work, there is seldom sufficient market incentive or social leverage to adopt voluntary codes of conduct. As a result of these limitations, the uptake of voluntary codes of conduct is generally poor in the ornamental nursery industry (Burt *et al.* 2007; Hulme 2015b).

In addition, voluntary codes of conduct need to be supported by evidence-based and independent advice regarding which plant species currently on the global market are potentially invasive in a particular region, so as to prevent their import, distribution and sale. This requires risk assessments of many hundreds of species. Who should pay for this? While risk assessment costs might be funded through an industry levy, the industry can be resistant to such additional costs (Barbier *et al.* 2013). Furthermore, unless an importer has exclusive rights to the sale and distribution of a plant taxon there is no incentive for them to invest in costly risk assessment when their competitors would also benefit from the introduction without any financial outlay.

Consequently, whether the cost of weed-risk assessment is borne by industry (as in New Zealand) or by government (as in Australia) has a major influence on the deliberate introduction of alien species by industry. Since the late 1990s, New Zealand has approved fewer than 100 plant species for cultivation (EPA 2017), while over the same period more than 1500 alien species have been permitted entry into Australia (Riddle, Porritt & Reading 2008). While other models of funding exist, such as through NGOs (PlantRight 2017), the contrast between New Zealand and Australia suggests that when the cost of weed-risk assessment is borne by the ornamental industry it can be a barrier to importing new plant species but not when governments are prepared to cover the expense. However, government support is likely to be increasingly dependent on either compulsory adherence or voluntary codes of conduct that are widely supported, robust and verifiable. Can a change in consumer choice influence the industry to be more compliant?

Shifting consumer values towards native and non-invasive alien plant species

The majority of ornamental plants are purchased by the general public (Barney 2014). Governmental and non-governmental organisations are important procurers of ornamental plants but they generally account for a relatively small, and often specialist (e.g. native species) share of the market (Fig. 2). Thus, educating the general public to make informed choices towards purchasing native or non-invasive plant species is often seen as the main mechanism through which consumers can reduce the risk of alien plant invasions (Reichard & White 2001). Conservation NGOs are increasingly working with the ornamental nursery industry to remove potentially invasive plants from sale and promote native or non-invasive alternatives through programmes such as PlantRight in the USA and “Grow Me Instead!” in Australia (Niemiera & Von Holle 2009; Drew, Anderson & Andow 2010). Nevertheless, many consumers have a preference for alien plant species over natives (Brzuszek & Harkess 2009; Kauth & Perez 2011) making choices based on flower size, colour and foliage attributes (Kendal, Williams & Williams 2012; Verbrugge *et al.* 2014). Promoting non-invasive alien plants as alternatives can also be problematic since the attributes the public look for in ornamental plants (e.g. consistent performance, generalist growing requirement, resistance to pests or diseases and requiring little maintenance) are traits that can also facilitate plant invasions (Hulme 2011). Consumers are sensitive to price, and preferences for native and alien plants may shift where cost differentials are sufficiently large (Yue, Hurley & Anderson 2011). However, differential pricing would either require governments to impose some form of environmental tax or for the industry to agree to consistent minimum pricing of potentially invasive alien plants, neither of which appears a particularly viable option (Barbier *et al.* 2013).

Booklets promoting alternative species, popular magazine articles highlighting invasive ornamentals, factsheets describing appropriate disposal of green waste, and even endorsements from celebrity gardeners all have a role to play in raising awareness about invasive ornamental plants (Marchante & Marchante 2016). However, behavioural change is more likely where the public have hands-on experience in the removal of invasive alien species from native ecosystems (Merenlender *et al.* 2016). If such activities could be sponsored by local ornamental nursery businesses and mobilise a volunteer workforce drawn from gardening clubs, horticultural societies and landscape professionals, this may be the groundswell needed to shift attitudes across the supply-chain.

Integration: can the whole be more than the sum of the parts?

The examination of four major policy instruments targeting the ornamental industry supply-chain highlights that while each has the potential to contribute to reducing the risk of plant invasions, none is sufficient on its own to stem the problem. However, integrating these policy instruments along the ornamental industry supply-chain would progressively reduce the risk more effectively. For most countries, there are few mechanisms to screen potentially invasive plant species before they enter the ornamental trade. This could be facilitated if the tracking, labelling and monitoring of plant imports were better harmonised with national regulations addressing plant health. Such activities would need to be supported by impartial and independent weed-risk assessment (Fig. 4).

While weed-risk assessment aims to determine whether a species should be accepted or rejected from import and/or sale, approximately 20% of species screened cannot usually be categorised with certainty (Riddle, Porritt & Reading 2008). Clear protocols need to be followed to deal with Accepted, Rejected and Uncertain species (Fig. 4). Accepted species, whether assessed pre- or post-border, should be added to a national whitelist and, upon entering the market, labelled as having a low likelihood of invasion (“Green” labelling) in order to reinforce public opinion regarding such risks. At the border, uncertain and rejected species should be prohibited from entry. For uncertain species, data gaps that might help reduce uncertainty should be identified and communicated to the industry, while rejected species are added to an appropriate blacklist (Fig. 4a). An increasing proportion of ornamental trade involves sales of cultivars and varieties yet a key area of uncertainty is whether subspecies and varieties should be assessed at the infraspecific or specific level. While weed risk assessment approaches are suitable for screening species at the infraspecific level that are true to type (Gordon *et al.* 2016) they do not account for the fact that non-invasive cultivars may revert back to invasive forms (Brand, Lehrer & Lubell 2012).

Management of risks post-border are more complicated due to species often being already under cultivation and/or established in the wild, which may result in industry opposition to extensive sales bans. To ensure effective and targeted legislation, legislated sales bans should focus on rejected species that have yet to become widely established in the wild (Fig. 4b). Such action on its own would not be sufficient to stem further spread and thus would need to be combined with an active eradication campaign. Rejected species that are already widespread outside of cultivation may best be targeted by voluntary sales bans supported by industry. Since voluntary bans may not be met with full compliance, such species would also need to be labelled as high risk species (“Red” labelling) to ensure purchasers could make informed choices. Eradication of these species would be infeasible but a programme of containment or control within high value environments would be recommended. Uncertain species would continue to be sold but labelled as intermediate risk (“Amber” labelling) until more information becomes available to point to higher or lower risk. Monitoring to ensure there was no evidence of establishment in natural areas would be key to species retaining “Amber” labelling.

While the important role of government, industry and the public in stemming the threat from invasive alien plants is well recognised, there has been little guidance to date as to how actions appropriate for each stakeholder could be better coordinated and more complementary. The foregoing scheme (Fig. 4) proposes a clearer mechanism for integration but its delivery will require the development of closer partnerships between government, NGOs and industry, perhaps through a joint body that oversees the outcomes of independent weed-risk assessment, advances the effectiveness of codes of conduct, informs priorities for sales bans, endorses appropriate labelling, and promotes consumer education. Closing the plant invasion pathway associated with ornamental horticulture requires government-industry agreements to fund effective pre- and post-border weed-risk assessments that can be subsequently supported by widely adopted, as well as verifiable, industry codes of conduct. This will ensure producers and consumers make informed choices in the face of better targeted public education addressing plant invasions.

Authors’ contributions

PEH conceived the ideas and led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Data accessibility

Data have not been archived because all data presented are in the public domain.

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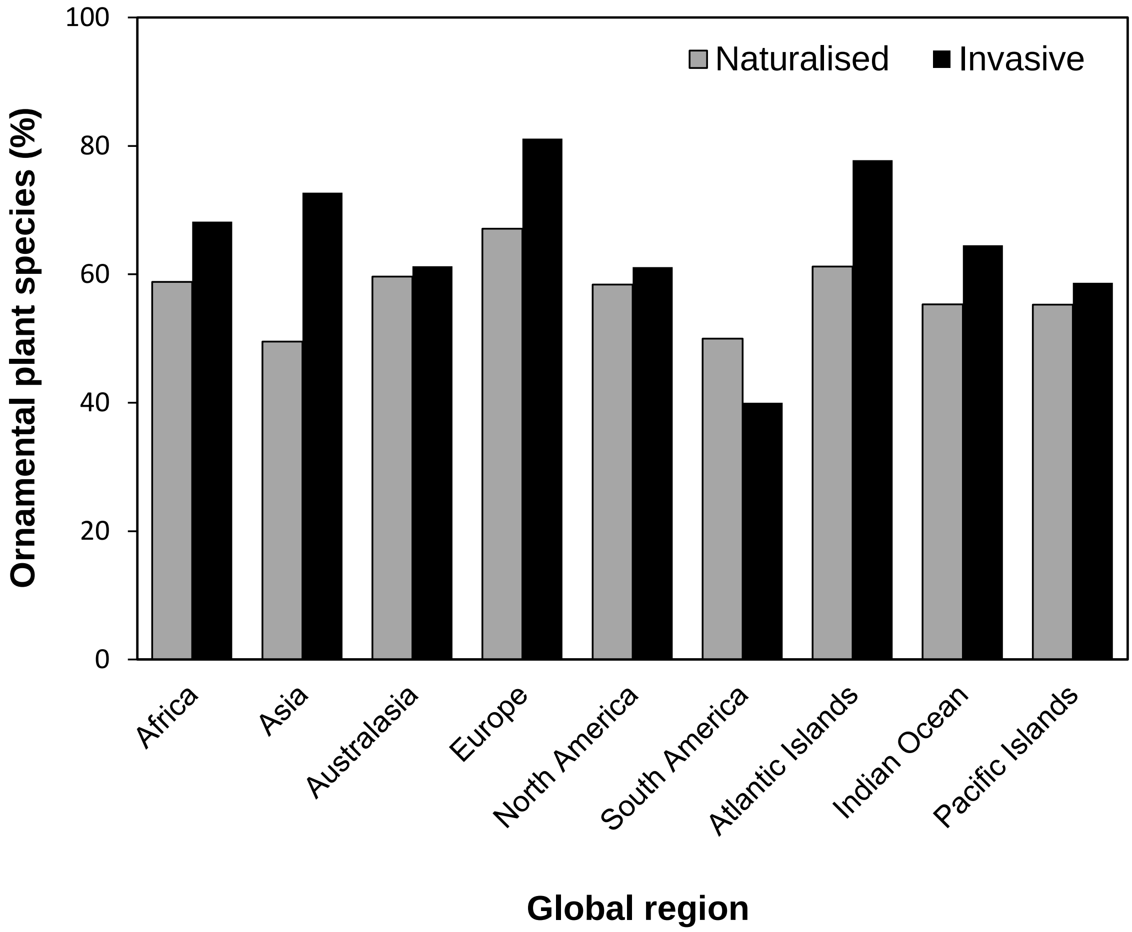
Figure Legends

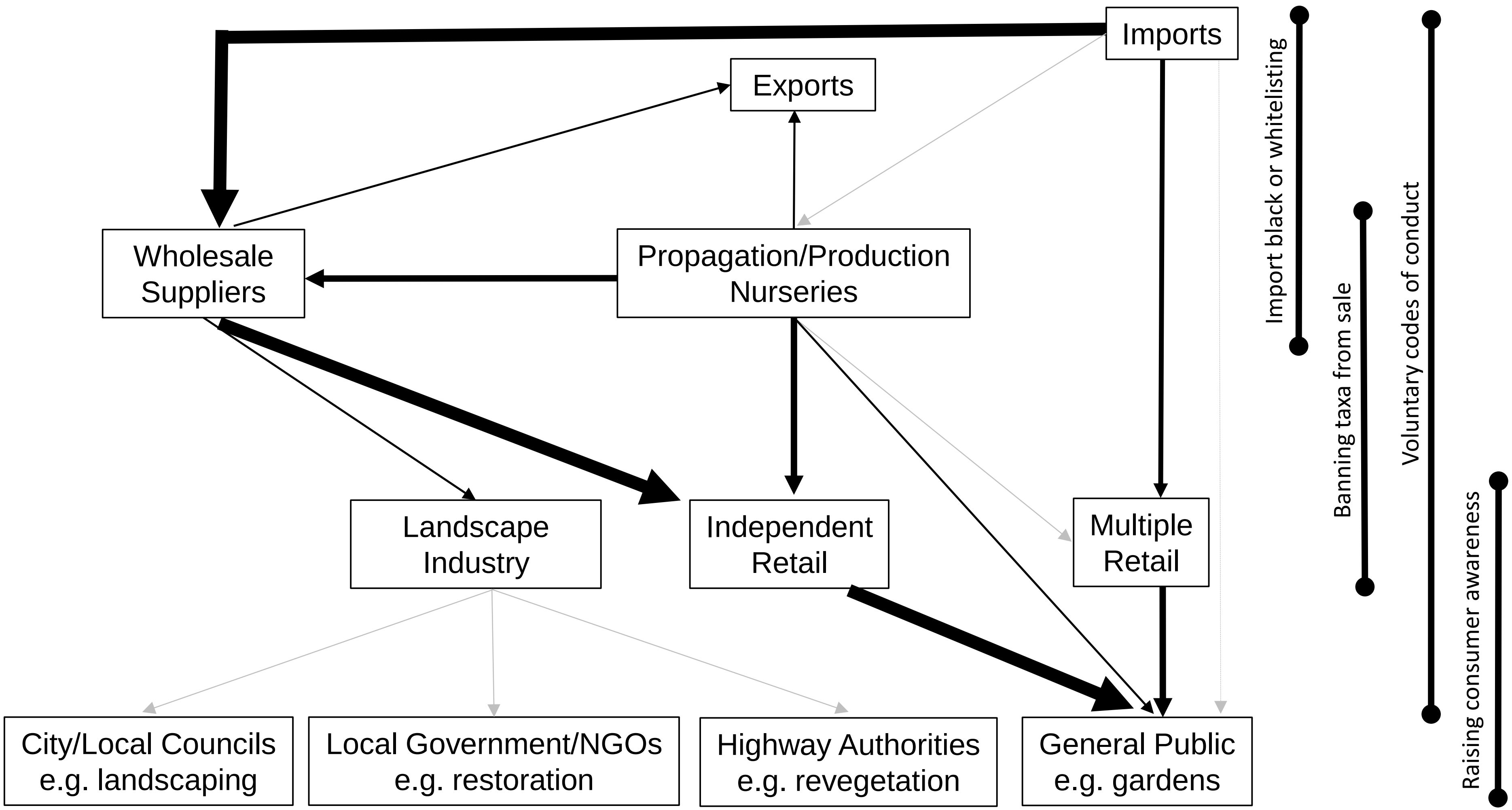
Figure 1. The percentage of 450 alien plant species that are listed as established or invasive in one or more regions of the world and that have been introduced through ornamental horticulture. The term invasive refers to an alien species established in natural or semi-natural ecosystems that is an agent of change threatening native biodiversity. Data and definitions are from Weber (2003).

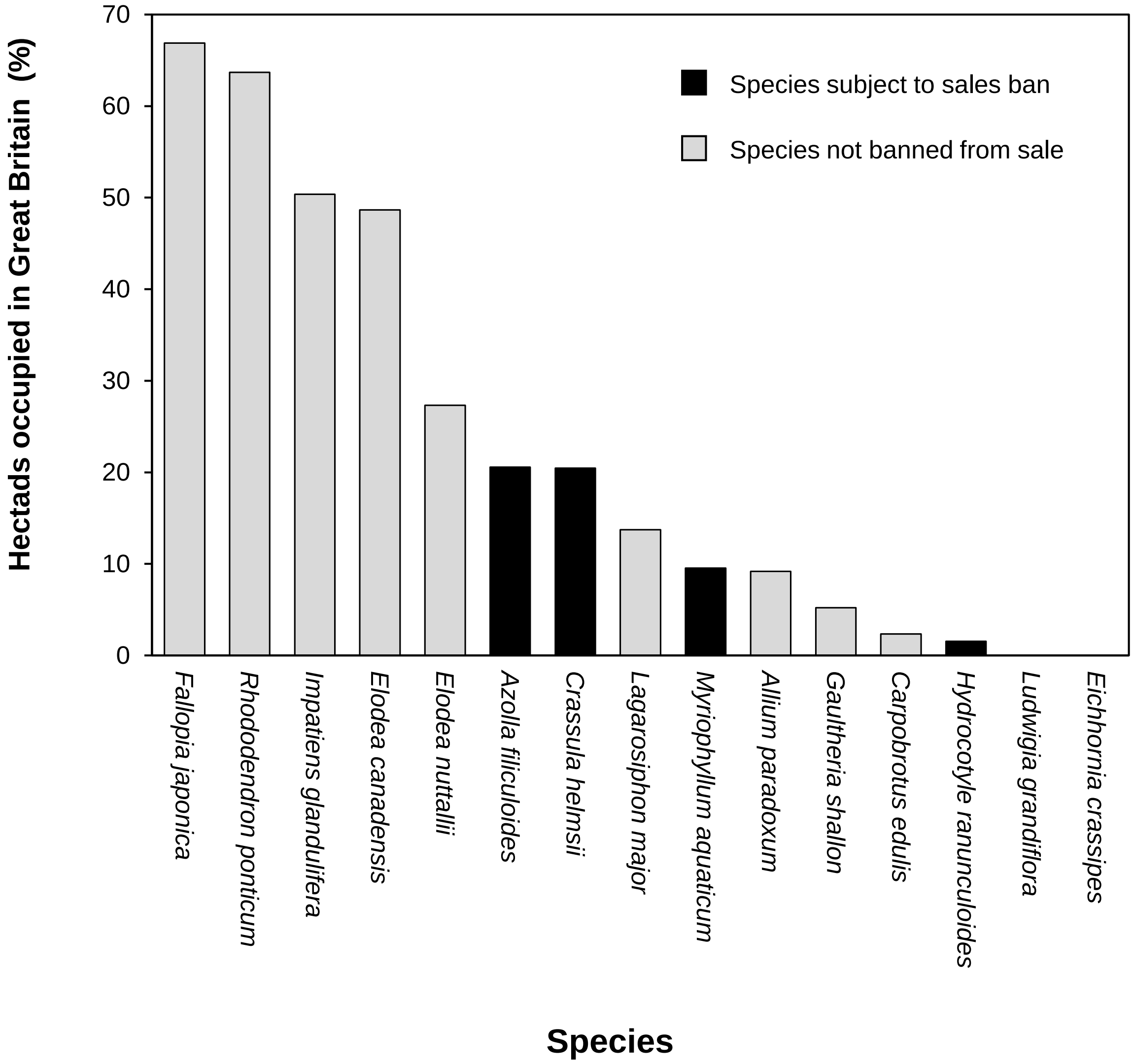
Figure 2. Schematic illustration of the ornamental nursery supply-chain identifying the route of alien germplasm from import, through propagation, to retail and subsequent use. The size and shading of the arrows represent the relative magnitude of the flows between each component and are based on financial data from Great Britain (Barney 2014). The domain of four major policy instruments across the supply-chain is also depicted.

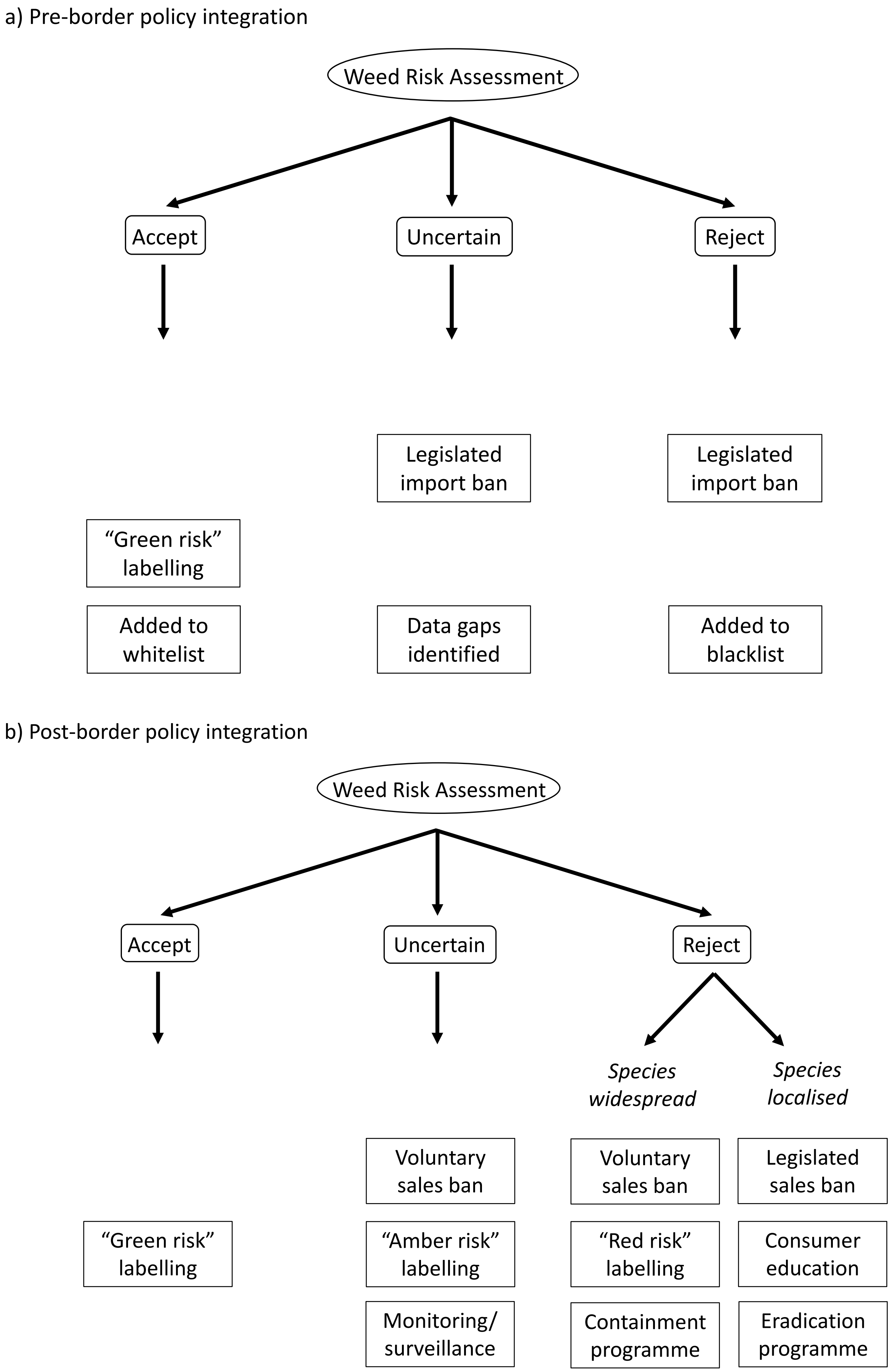
Figure 3. Fifteen plant species proposed for a sales ban (Defra 2007) and the percentage of hectads (10 × 10 km grid cells) in which each occurs in Great Britain (data.nbn.org.uk). Species finally banned from sale are highlight in by black bars with the exception of *Ludwigia grandiflora* which is present in < 1% of hectads.

Figure 4. Schematic representation of how different policy instruments can be integrated for different categories of plant species screened following weed-risk assessment either a) pre-border or b) post-border.


Naturalised
Invasive
Ornamental plant species (%)
0
20
40
60
80
100
Africa
Asia
Australasia
Europe
North America
South America
Atlantic Islands
Indian Ocean
Pacific Islands
Global region


Imports
Exports
Wholesale Suppliers
Propagation/Production Nurseries
Landscape Industry
Independent Retail
Multiple Retail
City/Local Councils e.g. landscaping
Local Government/NGOs e.g. restoration
Highway Authorities e.g. revegetation
General Public e.g. gardens
Import black or whitelisting
Banning taxa from sale
Voluntary codes of conduct
Raising consumer awareness


Species subject to sales ban
Species not banned from sale
Hectads occupied in Great Britain (%)
70
60
50
40
30
20
10
0
Fallopia japonica
Rhododendron ponticum
Impatiens glandulifera
Elodea canadensis
Elodea nuttallii
Azolla filiculoides
Crassula helmsii
Lagarosiphon major
Myriophyllum aquaticum
Allium paradoxum
Gaultheria shallon
Carpobrotus edulis
Hydrocotyle ranunculoides
Ludwigia grandiflora
Eichhornia crassipes
Species


a) Pre-border policy integration
Weed Risk Assessment
Accept
Uncertain
Reject
Legislated import ban
Legislated import ban
"Green risk" labelling
Added to whitelist
Data gaps identified
Added to blacklist
b) Post-border policy integration
Weed Risk Assessment
Accept
Uncertain
Reject
Species widespread
Species localised
Voluntary sales ban
Voluntary sales ban
Legislated sales ban
"Green risk" labelling
"Amber risk" labelling
"Red risk" labelling
Consumer education
Monitoring/ surveillance
Containment programme
Eradication programme