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

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65 **Summary**

66 1. Ornamental horticulture is the primary pathway for invasive alien plant
67 introductions. We critically appraise published evidence on the effectiveness
68 of four policy instruments that tackle invasions along the horticulture supply-
69 chain: pre-border import restrictions, post-border bans, industry codes of
70 conduct, and consumer education.

71 2. Effective pre-border interventions rely on rigorous risk assessment and high
72 industry compliance. Post-border sales bans become progressively less
73 effective when alien species become widespread in a region.

74 3. A lack of independent performance evaluation and of public disclosure, limits
75 the uptake and effectiveness of voluntary codes of conduct and discourages
76 shifts in consumer preference away from invasive alien species.

77 4. *Policy implications.* Closing the plant invasion pathway associated with
78 ornamental horticulture requires government-industry agreements to fund
79 effective pre- and post-border weed-risk assessments that can be
80 subsequently supported by widely adopted, as well as verifiable, industry
81 codes of conduct. This will ensure producers and consumers make informed
82 choices in the face of better targeted public education addressing plant
83 invasions.

84

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

87

88 Introduction

89 The global trade in ornamental nursery stock is the dominant pathway by which
90 invasive alien plants have been introduced worldwide (Lambdon *et al.* 2008; Jiang *et al.*
91 *et al.* 2011; Lehan *et al.* 2013; Dodd *et al.* 2015; Rojas-Sandoval & Acevedo-Rodriguez
92 2015; Faulkner *et al.* 2016). This is not surprising since the ornamental nursery trade
93 (comprising commerce in finished, bareroot and seedling trees, shrubs, ground
94 covers, grasses, vines and aquatic plants of sale size, bulbs and seeds) is largely
95 built around commerce in alien plant species, their hybrids, cultivars and varieties
96 (Drew, Anderson & Andow 2010). Alien species often represent a higher proportion
97 than native species in terms of what is cultivated, the available stock in retail outlets
98 and consumer purchases. For example, in both Great Britain and New Zealand,
99 there is an order of magnitude greater number of plant species in cultivation than
100 native plant species in the wild (Gaddum 1999; Armitage *et al.* 2016). In the USA,
101 alien species comprise as much as 80% of the stock held by nurseries (Brzuszek &
102 Harkess 2009; Harris *et al.* 2009) and account for up to 90% of nursery revenue
103 (Kauth & Perez 2011). While only a relatively small proportion of taxa escape
104 cultivation, often less than 10% (Hulme 2012), the sheer number of taxa cultivated
105 results in the ornamental pathway being the main source of naturalised and invasive
106 alien plant species in natural areas worldwide (Fig. 1).

107 Annual sales of nursery stock amount to US\$430 million in Canada (Agriculture-
108 Canada 2015), US\$500 million in Australia (PHA 2015), US\$1,054 million in the
109 United Kingdom (Defra 2016) and US\$4,267 million in the USA (USDA 2014).
110 Policymakers could therefore argue that plant invasions are an unavoidable minor
111 cost incurred to support an industry that delivers significant economic benefits and
112 brings pleasure to millions of gardeners. But can appropriate policies be designed to

113 target the ornamental nursery industry supply-chain such that changes to operations
114 to mitigate invasions will be most easy to implement, cost-effective and acceptable?

115 **Integrating invasive species policy across the ornamental plant supply-chain**

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

128 Actors within the ornamental nursery industry have different motivations, knowledge
129 of invasive plant species and enthusiasm for market change (Humair, Kueffer &
130 Siegrist 2014). Thus while several policies exist addressing plant invasions arising
131 from ornamental horticulture (Reichard & White 2001; Barbier *et al.* 2013), they have
132 seldom been viewed as an integrated suite of options targeting different actors
133 (Drew, Anderson & Andow 2010). Preventing the introduction or establishment of
134 potentially invasive alien species is often the most cost-effective and environmentally
135 desirable policy option to manage invasions (Keller, Lodge & Finnoff 2007). The
136 ornamental industry supply-chain can be used to assess the merit of four major
137 policy instruments targeting prevention: pre-border import restrictions; post-border

138 plant sales bans (both affecting breeders, propagators and producers); industry
139 codes of conduct (adopted by trade and public retail outlets); and tools to engender
140 consumer behavioural change through increased public awareness.

141 **Pre-border restrictions on the import of invasive plants**

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

155 Furthermore, without mechanisms to check compliance, particularly in the face of
156 increasing internet trade in invasive alien species (Humair *et al.* 2015) and poor
157 species identification (Thum, Mercer & Wcisel 2012), both blacklists and whitelists
158 can be easily bypassed. Whereas in New Zealand all incoming travellers, shipping
159 containers and mail items are screened for potential risk goods, this is not the case
160 in most other countries where national borders are more porous and the biosecurity
161 infrastructure less effective. As a consequence, legislation often has to be updated
162 retrospectively following the discovery that a previously introduced species has

163 become invasive in the territory. Under these circumstances, policy considerations
164 shift from prohibiting entry towards preventing the wider dissemination and spread of
165 species already in cultivation.

166 **Post-border banning of invasive plant species from sale**

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

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

201 **Codes of conduct and industry self-regulation**

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

210 An important aspect of any voluntary code of conduct is that there should be
211 consequences for non-compliance in terms of bad publicity and brand image. This
212 requires that suppliers and customers can readily identify actors participating in

213 voluntary codes of conduct and would involve procedures to audit compliance
214 reasonably frequently. Therefore, while it is crucial to monitor and evaluate the
215 performance of codes of conduct, and to ensure public disclosure, these actions
216 have never been included in voluntary codes of conduct for the ornamental nursery
217 industry. As there are no means of assessing how well the codes work, there is
218 seldom sufficient market incentive or social leverage to adopt voluntary codes of
219 conduct. As a result of these limitations, the uptake of voluntary codes of conduct is
220 generally poor in the ornamental nursery industry (Burt *et al.* 2007; Hulme 2015b).

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

230 Consequently, whether the cost of weed-risk assessment is borne by industry (as in
231 New Zealand) or by government (as in Australia) has a major influence on the
232 deliberate introduction of alien species by industry. Since the late 1990s, New
233 Zealand has approved fewer than 100 plant species for cultivation (EPA 2017), while
234 over the same period more than 1500 alien species have been permitted entry into
235 Australia (Riddle, Porritt & Reading 2008). While other models of funding exist, such
236 as through NGOs (PlantRight 2017), the contrast between New Zealand and
237 Australia suggests that when the cost of weed-risk assessment is borne by the

238 ornamental industry it can be a barrier to importing new plant species but not when
239 governments are prepared to cover the expense. However, government support is
240 likely to be increasingly dependent on either compulsory adherence or voluntary
241 codes of conduct that are widely supported, robust and verifiable. Can a change in
242 consumer choice influence the industry to be more compliant?

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

244 The majority of ornamental plants are purchased by the general public (Barney
245 2014). Governmental and non-governmental organisations are important procurers
246 of ornamental plants but they generally account for a relatively small, and often
247 specialist (e.g. native species) share of the market (Fig. 2). Thus, educating the
248 general public to make informed choices towards purchasing native or non-invasive
249 plant species is often seen as the main mechanism through which consumers can
250 reduce the risk of alien plant invasions (Reichard & White 2001). Conservation
251 NGOs are increasingly working with the ornamental nursery industry to remove
252 potentially invasive plants from sale and promote native or non-invasive alternatives
253 through programmes such as PlantRight in the USA and “Grow Me Instead!” in
254 Australia (Niemiera & Von Holle 2009; Drew, Anderson & Andow 2010).
255 Nevertheless, many consumers have a preference for alien plant species over
256 natives (Brzuszek & Harkess 2009; Kauth & Perez 2011) making choices based on
257 flower size, colour and foliage attributes (Kendal, Williams & Williams 2012;
258 Verbrugge *et al.* 2014). Promoting non-invasive alien plants as alternatives can also
259 be problematic since the attributes the public look for in ornamental plants (e.g.
260 consistent performance, generalist growing requirement, resistance to pests or
261 diseases and requiring little maintenance) are traits that can also facilitate plant
262 invasions (Hulme 2011). Consumers are sensitive to price, and preferences for

263 native and alien plants may shift where cost differentials are sufficiently large (Yue,
264 Hurley & Anderson 2011). However, differential pricing would either require
265 governments to impose some form of environmental tax or for the industry to agree
266 to consistent minimum pricing of potentially invasive alien plants, neither of which
267 appears a particularly viable option (Barbier *et al.* 2013).

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

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

279 The examination of four major policy instruments targeting the ornamental industry
280 supply-chain highlights that while each has the potential to contribute to reducing the
281 risk of plant invasions, none is sufficient on its own to stem the problem. However,
282 integrating these policy instruments along the ornamental industry supply-chain
283 would progressively reduce the risk more effectively. For most countries, there are
284 few mechanisms to screen potentially invasive plant species before they enter the
285 ornamental trade. This could be facilitated if the tracking, labelling and monitoring of
286 plant imports were better harmonised with national regulations addressing plant

287 health. Such activities would need to be supported by impartial and independent
288 weed-risk assessment (Fig. 4).

289 While weed-risk assessment aims to determine whether a species should be
290 accepted or rejected from import and/or sale, approximately 20% of species
291 screened cannot usually be categorised with certainty (Riddle, Porritt & Reading
292 2008). Clear protocols need to be followed to deal with Accepted, Rejected and
293 Uncertain species (Fig. 4). Accepted species, whether assessed pre- or post-border,
294 should be added to a national whitelist and, upon entering the market, labelled as
295 having a low likelihood of invasion (“Green” labelling) in order to reinforce public
296 opinion regarding such risks. At the border, uncertain and rejected species should be
297 prohibited from entry. For uncertain species, data gaps that might help reduce
298 uncertainty should be identified and communicated to the industry, while rejected
299 species are added to an appropriate blacklist (Fig. 4a). An increasing proportion of
300 ornamental trade involves sales of cultivars and varieties yet a key area of
301 uncertainty is whether subspecies and varieties should be assessed at the
302 infraspecific or specific level. While weed risk assessment approaches are suitable
303 for screening species at the infraspecific level that are true to type (Gordon *et al.*
304 2016) they do not account for the fact that non-invasive cultivars may revert back to
305 invasive forms (Brand, Lehrer & Lubell 2012).

306 Management of risks post-border are more complicated due to species often being
307 already under cultivation and/or established in the wild, which may result in industry
308 opposition to extensive sales bans. To ensure effective and targeted legislation,
309 legislated sales bans should focus on rejected species that have yet to become
310 widely established in the wild (Fig. 4b). Such action on its own would not be sufficient
311 to stem further spread and thus would need to be combined with an active

312 eradication campaign. Rejected species that are already widespread outside of
313 cultivation may best be targeted by voluntary sales bans supported by industry.
314 Since voluntary bans may not be met with full compliance, such species would also
315 need to be labelled as high risk species (“Red” labelling) to ensure purchasers could
316 make informed choices. Eradication of these species would be infeasible but a
317 programme of containment or control within high value environments would be
318 recommended. Uncertain species would continue to be sold but labelled as
319 intermediate risk (“Amber” labelling) until more information becomes available to
320 point to higher or lower risk. Monitoring to ensure there was no evidence of
321 establishment in natural areas would be key to species retaining “Amber” labelling.

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

336 **Authors’ contributions**

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

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349 **Data accessibility**

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

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500

501 **Figure Legends**

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

507

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

514

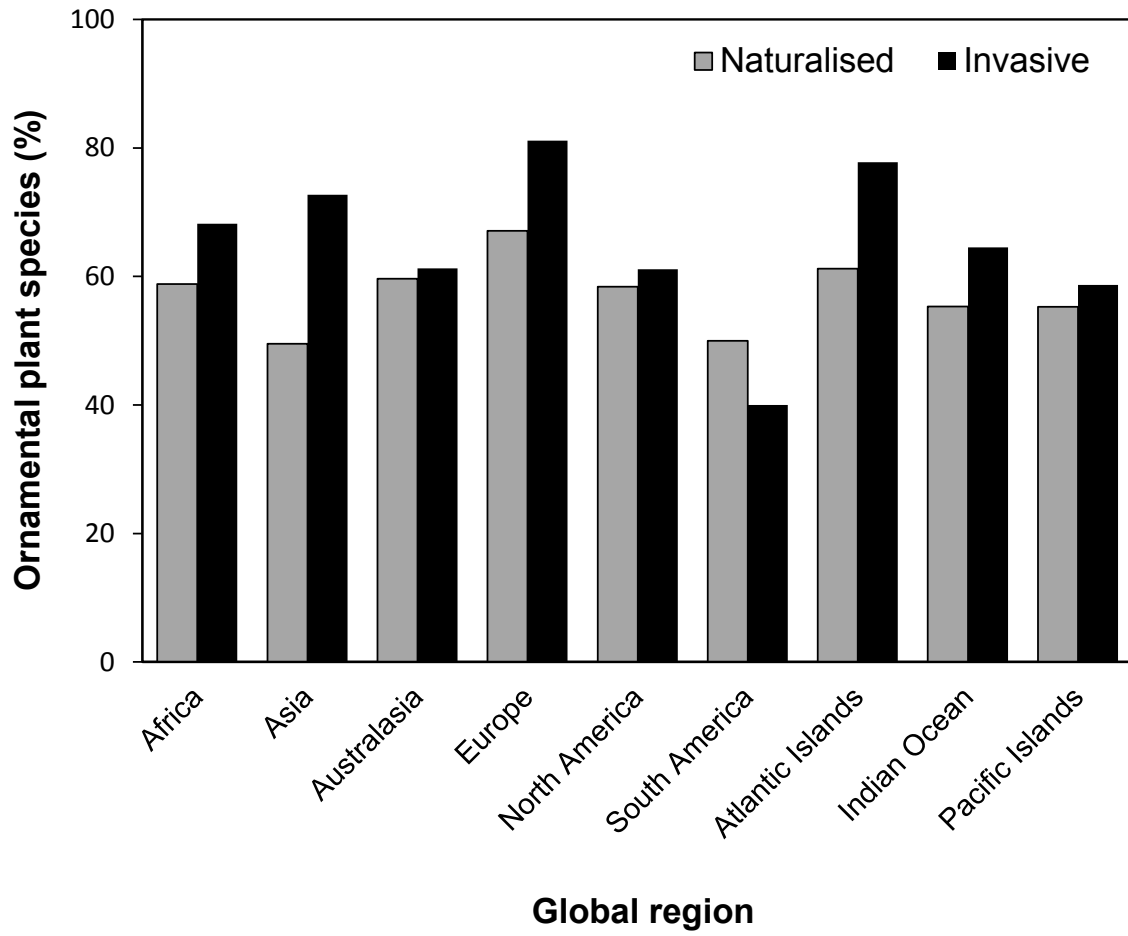
515 **Figure 3.** Fifteen plant species proposed for a sales ban (Defra 2007) and the
516 percentage of hectads (10 × 10 km grid cells) in which each occurs in Great Britain
517 (data.nbn.org.uk). Species finally banned from sale are highlight in by black bars with
518 the exception of *Ludwigia grandiflora*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

519

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

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