Developing a risk assessment tool for evaluating potential invasiveness of ornamental plants©

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INTRODUCTION

This article summarizes *PRE Model Research*, published by PLOS ONE, March 2015, and led by C. Conser[1], L. Seebacher[2], D.W. Fujino[3], S. Reichard[4], J.M. DiTomaso[1] ([1]Department of Plant Sciences, University of California Davis, Davis, California, USA; [2]Washington State Department of Ecology, Lacey, Washington, USA; [3]University of California, Davis, Center for Urban Horticulture, Davis, California, USA; [4]University of Washington Botanic Gardens, Seattle, Washington, USA).

The nursery and landscape industry has introduced over 50,000 ornamental species in the United States (Gordon and Gantz, 2008). The total number of cultivars introduced increased from 29,000 in 1987 to 105,000 in 2008 (Levine and D'Antonio, 2003). Most of these species and cultivars do not cause environmental or economic problems. In fact, only a small percentage (between 0.1 and 1%) has become invasive.

However, of the species that are invasive in the USA, many originated from the horticultural industry. For example, in California, 60% of the 214 invasive plants impacting wildlands were intentionally introduced for human uses, and 47% of those plants are landscape ornamentals (Cal-IPC, 2014). Throughout North America, 82% of the 235 invasive woody plants are horticultural in origin (Reichard and Hamilton, 1997) and in the estimates of invasives originating from the nursery industry range from 34 to 83% (Bell et al., 2003).

The most cost effective way to avoid establishment of new invasive ornamental plants is to prevent their introduction at the beginning of the nursery supply chain. This can be achieved through risk assessment tools. Weed Risk Assessment (WRA) is a systematic process that uses available evidence to estimate the risk of a plant species becoming invasive in a given region. While there are many WRA tools that have been developed for a variety of applications, including evaluating plants in botanical gardens, none were specifically designed to screen ornamental plants prior to being released into the environment.

The most widely used WRA tool was developed in Australia (Pheloung et al., 1999) for import screening purposes, and has since been adapted for use in other parts of the world. The tool consists of 49 questions. It has been shown to be 90 to 100% accurate in correctly identifying invasive plants, but results varied dramatically from 21 to 75% accuracy in categorizing known, non-invasive plants. As a result, the tool is considered by the horticultural industry to be too conservative in predicting invasiveness, with far too many non-invasive species categorized as invasive. This will likely reduce its practical application by the industry.

The United States (US) also has a WRA tool used by USDA-APHIS to prevent the importation of invasive plants (Koop et al., 2011). Unlike the Australian WRA, this tool has high accuracy in classifying both major-invaders (94% accuracy) and non-invaders (97% accuracy), but it is not designed for evaluating potential invasiveness on a regional scale or for determining invasive risk with plants in the early pre-marketing stages.

For the nursery and landscape industry to consider a WRA tool useful, it must be: highly accurate in predicting potential invasiveness and non-invasiveness, easy to use, and not require a long period to complete the assessment process. Thus, we initiated a project using a science-based and systematic process to develop a highly accurate (for both invasive and non-invasive plants) Plant Risk Evaluation (PRE) tool specifically for screening

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ornamental plants.

MATERIALS AND METHODS

We assessed questions from existing WRA tools and developed the PRE tool with the most predictive and statistically relevant questions for ornamental plants. The ultimate goal of this project is to provide the horticultural industry with a voluntary screening tool that prevents new, high-risk plants from being introduced or sold in regions where the plants are likely to become invasive.

The initial step in developing the PRE tool required an evaluation of several existing WRA screening tools to determine the most appropriate and highly predictive questions, contributing to model accuracy for ornamental plants. From the various tools available we identified 56 questions that were commonly used to evaluate a set of known invasive and known non-invasive plants. These questions covered invasive history, climate match, difficulty of control, environmental impacts, reproductive and dispersal strategies, and growth rate.

Using the 56 questions, we evaluated a total of 35 plants, 21 known invasive and 14 known non-invasive plants. The invasive plants were selected from the California Invasive Plant Council's (Cal-IPC) Invasive Plant Inventory and the non-invasive species were chosen from the Plant Right's Suggested Alternatives for Invasive Garden Plants (PlantRight, 2014). As many questions as possible were answered using available literature, as well as searches of online databases and species' fact sheets.

For each plant species evaluated, we calculated the total score and the percentage of questions that were answered. To determine which questions contributed most to the predictability of invasiveness and non-invasiveness, we used a two-tailed Fischer's Exact Test, which statistically compared the answers for each question between the known invasive and non-invasive species. In addition, we calculated the percentage of times each question was answered for all known invasive and non-invasive plants. The scores for known invasive plants ranged from 21 to 44, with an average score of 31. The scores for known non-invasive plants ranged from 5 to 14, with an average score of 10. For each plant species screened, the percentage of questions answered for known invasive plants ranged from to 80% to 98%, with an average of 90%. The percentage of questions answered for known non-invasive plants ranged from to 86 to 95%, with an average of 89%.

The Fischer's Exact Test identified a total of 31 questions that had a greater than 95% probability of separating invasive from non-invasive species. The percentage of times each of the 56 questions was answered for known invasive plants ranged from 5 to 100%. The percentage of times each of the 56 questions was answered for known non-invasive plants ranged from to 0 to 100%. Of the 56 questions evaluated, 17 were eliminated because they did not provide statistically significant predictive power to separate known invasive from known non-invasive plants. Other questions were eliminated because they could not be answered at a high enough frequency (only 0 to 19%), they were irrelevant to evaluating ornamental plants or new plant introductions (mostly environmental impact related questions), or the question was inherently biased. For example, the question was only known and answered when the phenomenon was studied, which was nearly always with known invasive species (i.e., allelopathy, palatability to animals, impacts on grazing).

After removing or merging questions, we were left with a PRE tool that contained 19 questions (Table 1). We tested the 19-question PRE tool by screening 94 additional plants, 57 known invasive and 37 known non-invasive plants. Similar to the 56 original questions, we used a two-tailed Fischer's Exact Test to compare the predictability of each question and calculated the number and percentage of times each question was answered. From the analysis, 16 of the 19 questions showed statistical significance between the known invasive and known non-invasive species.

Similar to the same questions in the 56-question evaluation, each question was answered at a high frequency, ranging from a low of 54% for non-invasive plants to 100% for most other questions. An average of 97% of the questions were answered for both invasive and non-invasive plants for the 94 species evaluated. For individual species, this ranged from 85 to 100% of the questions answered.

Table 1. PRE tool questions and their statistical predictability in separating known invasive and non-invasive species. Fisher's Exact Test compared the 57 invasive species against the 37 non-invasive species for each question. Percent of each question (Q) answered is also included. Brackets after question indicate citation were question is included in WRA model.

Question	Question in PRE tool	Fisher's exact test (2-tail)	% Q was answered for invasive plants	% Q was answered for non-invasive plants	Point values Yes/No
1	Has the species become naturalized where it is not native (Koop, et al., 2011; Pheloung et al., 1999; Brunel et al., 2010; Caley and Kuhnert, 2006)?	*P*<0.0001*	100	100	1/0
2	Is the species noted as being invasive elsewhere in the US or world in a similar climate? (Reichard and White, 2001; Koop, et al., 2011; Virtue et al., 2008; Caley and Kuhnert, 2006)?	*P*<0.000 1*	100	100	2/0
3	Is the species noted as being invasive elsewhere in the US or world in a similar climate (Reichard and White, 2001; Koop, et al., 2011; Virtue et al., 2008; Brunel et al., 2010; Caley and Kuhnert, 2006)?	*P*<0.0001*	100	100	3/0
4	Are other species of the same genus invasive in other areas with a similar climate (Reichard and White, 2001; Koop, et al., 2011; Virtue et al., 2008; Caley and Kuhnert, 2006)?	*P*<0.0001*	100	100	1/0
5	Is the species found predominately in a climate that matches those within the region of introduction (Koop, et al., 2011; Pheloung et al., 1999; Brunel et al., 2010)?	-	96	100	2/0
6	Dominates in areas this species has already invaded (displaces natives) (Koop, et al., 2011; Virtue et al., 2008; Brunel et al., 2010; Caley and Kuhnert, 2006). Can overtop and/or smother surrounding vegetation (Koop, et al., 2011; Virtue et al., 2008; Pheloung et al., 1999; Caley and Kuhnert, 2006).	*P*<0.0001*	100	100	1/0
7	Is the plant noted as being highly flammable and/or promotes fire and/or changes fire regimes (Koop, et al., 2011; Virtue et al., 2008; Pheloung et al., 1999; Caley and Kuhnert, 2006)?	*P*<0.0001*	79	97	1/0
8	Is the plant a health risk to humans or animals/fish (Toxic tendencies) (Koop, et al., 2011; Virtue et al., 2008; Pheloung et al., 1999; Brunel et al., 2010; Caley and Kuhnert, 2006)? Has the species been noted as impacting agricultural/grazing systems (Koop, et al., 2011; Pheloung et al., 1999; Brunel et al., 2010)?	*P*=0.0001*	100	100	1/0

Table 1. Continued.

Question	Question in PRE tool	Fisher's exact test (2-tail)	% Q was answered for invasive plants	% Q was answered for non-invasive plants	Point values Yes/No
9	Does the plant produce impenetrable thickets, blocking or slowing movement (Koop, et al., 2011; Virtue et al., 2008; Pheloung et al., 1999; Caley and Kuhnert, 2006)?	*P*=0.0002*	93	100	1/0
10	Reproduces vegetatively via root sprouts/suckers (Reichard and White, 2001; Pheloung et al., 1999) or stem/trunk sprouts/coppicing (Reichard and White, 2001; Koop, et al., 2011).	*P*=0.0314*	98	100	1/0
11	Plant fragments are capable of producing new plants (Reichard and White, 2001; Pheloung et al., 1999).	*P*=0.0002*	100	100	1/0
12	Does the plant produce viable seed?	*P* =0.0001*	100	100	1/0
13	Produces copious viable seeds each year (>1000) (Reichard and White, 2001; Pheloung et al., 1999).	*P*<0.0001*	86	78	1/0
14	Seeds quick to germinate (Reichard and White, 2001; Pheloung et al., 1999).	*P*=0.1296	75	68	1/0
15	Short juvenile period. Produces seeds in first 3 years (herbaceous) or produces seeds in first five years (woody) (Reichard and White, 2001; Pheloung et al., 1999).	*P*=0.0078*	89	54	1/0
16	Long flowering period with seeds produced for more than 3 months each year (Reichard and White, 2001; Pheloung et al., 1999).	*P*=0.2320	86	86	1/0
17	Propagules dispersed by mammals/insects or birds or via domestic animals (Koop, et al., 2011; Virtue et al., 2008; Pheloung et al., 1999).	*P*<0.0001*	100	97	1/0
18	Propagules dispersed by wind or water (Koop, et al., 2011; Virtue et al., 2008; Pheloung et al., 1999).	*P*<0.0001*	98	97	1/0
19	Propagules dispersed via agriculture, contaminated seed, farm equipment, vehicles or boats, or clothing/shoes (Koop, et al., 2011; Virtue et al., 2008; Pheloung et al., 1999; Caley and Kuhnert, 2006).	*P*<0.0001*	100	94	1/0
		Average	97	97	Range of 23/0

RESULTS

The results showed scores for known invasive plants ranging from 12 to 21, while the scores for known non-invasive plants ranging from 2 to 13. Based on the separation in scores among the known invasive and non-invasive species, the scoring scale for the 19-question PRE tool was established to be: <11 as an “Accept” (low invasive risk); 11 to 13 as “Evaluate Further”; and, >13 as a “Reject” (high invasive risk) (Figure 1). Plants which fell into the “evaluate further” category may need additional assessment by an expert panel.

For the 57 known invasive plants evaluated through the 19-question PRE tool, no species were classified as accept. When species within the “evaluate further” category were excluded, the accuracy of the PRE tool in prediction invasiveness was 100%.

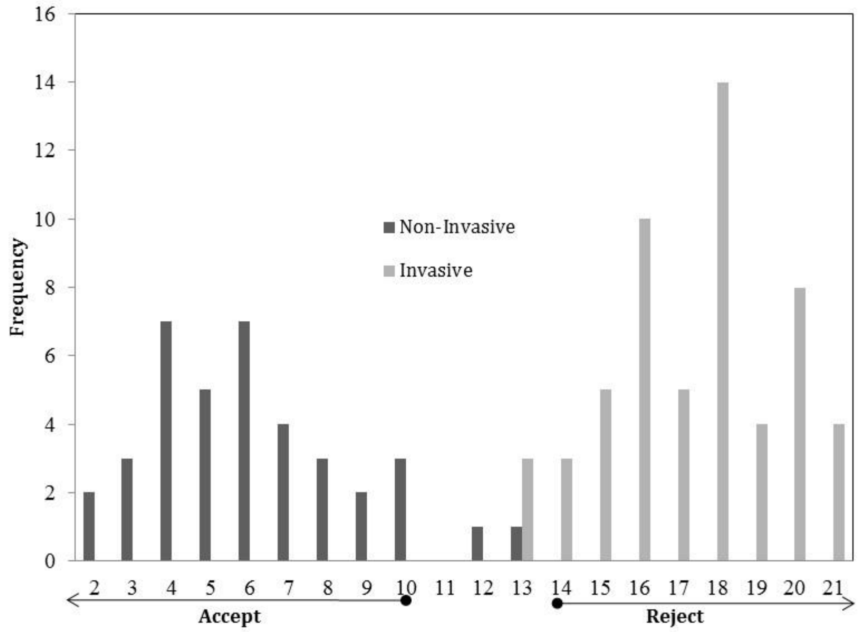

Figure 1. Histogram of scoring frequencies for 19-question PlantRight (PRE) tool. Scores: Invasive >13; Non-invasive <11; Evaluate Further = 11-13.

Even when the four species listed as "evaluate further" were considered false positives (invasive species incorrectly accepted as non-invasive) the accuracy and sensitivity was 93%. For the non-invasive species, the 19-question PRE tool gave no false negatives (non-invasive species rejected as invasive), but the tool did classify one species in the "evaluate further" category. Thus, the percent accuracy of the model when plants classified as "evaluate further" are excluded is 100%. Even when the "evaluate further" species are considered as false negatives, the accuracy is still a very high 97%.

When considering both known invasive and non-invasive species, the overall accuracy of the PRE tool model was 100% when "evaluate further " species were excluded and 95% when they were included.

NEXT STEPS

The next steps in the development and validation of the PlantRight PRE tool will be to: 1) test the consistency of the tool by different users (industry, academia, and conservation); 2) test the accuracy of the tool in evaluating invasive risk on a national scale (to demonstrate that it can be used beyond California, and at different scales); 3) incorporate climate matching capabilities; 4) develop an online PRE tool and database (https://pre.ice.ucdavis.edu) in partnership with UC Davis; and, 5) encourage voluntary nursery industry adoption. The ultimate goal of our PRE efforts is to equip members of the horticultural industry with a practical screening tool to prevent potentially high-risk plants from being introduced or sold in regions where they are likely to become invasive.

CONCLUSION

The PRE tool can be used preventatively by the nursery industry to screen ornamental plants for potential invasiveness prior to introduction to the marketplace. PRE can also predict the risk of invasiveness (low or high) for a given species or cultivar in a designated region.

The tool is expected to provide the industry with a variety of benefits, including: 1) a practical, efficient tool to accurately assess invasive risk, by region, early in the evaluation process (before making a significant economic investment); 2) a decision support tool to stay ahead of local and/or regional regulatory threats; 3) additional information regarding taxonomy, reproductive characteristics, culinary and medicinal uses; and, 4) optional services including an online PRE database (tiered access and password protected), and access to maps of climate-matching results under various assumptions (e.g., drought tolerance) and scenarios (e.g., irrigation, climate change).

Because invasive plants represent only a small percentage of the horticultural inventory (~1%), screening plants for invasive qualities should not present a major economic hardship to the industry. Pre-screening of potential introductions would be expected to categorize the vast majority of species as possessing low (or no) invasive risk, while identifying relatively few as having a high probability of becoming invasive.

More importantly, because development of new cultivars represents a significant economic investment for nursery growers throughout the US, pre-screening would prevent nurseries from spending important research dollars to develop new cultivars with high invasive potential. Rather, the tool could help industry promote exclusively non-invasive plants in regional markets.

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