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Predicting invasive plants: prospects for a general screening system based on current regional models

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Abstract

Screening systems for predicting invasive plants have been independently developed for the non-indigenous floras of North America, the South African fynbos, and Australia. To evaluate the performance of these screening systems outside the regions for which they were developed, we tested them for the non-indigenous flora of the Hawaiian Islands. When known invasive plant species in the Hawaiian Islands were evaluated using the North American and Australian systems, 82% and 93% of the species were predicted to be invasive, respectively, and the remainder were classified as requiring further study. The South African fynbos system correctly predicted only 60% of the invasive species in the Hawaiian Islands. All three screening systems correctly classified a majority of the non-invaders as non-invasive. The Australian system has several advantages over the other systems, including the highest level of correct identification of invaders (>90%), ability to evaluate non-woody plants, and ability to evaluate a species even when the answers to some questions are unknown. Nevertheless, with the Australian system, a large fraction of species known not to be invasive were recommended for further study before importing, so there remains room for improvement in identifying non-invasive species. Based on our results for the Hawaiian Islands and a previous evaluation in New Zealand, the Australian system appears to be a promising template for building a globally applicable system for screening out invasive plant introductions.

Introduction

Methods to accurately predict which alien plant introductions will become invasive (*sensu* Mack et al. 2000) are needed to make informed decisions about deliberate species introductions. As recently as the late 1980s, most analyses concluded that attempts at *a priori* prediction would be futile because no consistent set of characteristics was apparent among invaders (Crawley 1987; Noble 1989). Although there remain many reasons why predictions may fail (Williamson 1999), recent analysis of quantitative data and multivariate statistical methods have demonstrated that prediction of invaders is sometimes possible, at least within certain specific taxonomic groups, such as *Pinus* (Rejmanek and Richardson 1996). An alternative to the taxon-specific approach to predicting invaders has been to develop screening methods applicable to a wide range of taxonomic groups but focused on specific ecosystems or geographic regions. This approach was employed for woody invaders of North America (Reichard and Hamilton 1997), woody invaders of the South African fynbos (Tucker and Richardson 1995), and plant invaders of Australia (Pheloung et al. 1999). The Australian system was also tested in New Zealand after minor modification (Pheloung et al. 1999). These independently developed screening systems use various types of information (e.g. life history, biogeography, habitat characteristics and weed history) to classify a species as either likely to be invasive, not likely to be invasive, or requiring further study. Each of these screening systems identified invasive plants with a success rate of 70–90% in the region for which the screening system had been designed. Thus, during a period of less than five years, important advances have been made in developing methods for predicting plant invaders [but see Williamson (1999) for a discussion of shortcomings].

One approach for continued progress in predicting invasive pests would proceed with the independent development of screening systems for additional regions of the world. While this approach has been successful so far, independently developing specific screening systems for each region would require much time and expense. An alternative, more cost-effective approach would focus on one general screening system that could be applied broadly to many geographic regions, perhaps with minor region-specific modifications. Current region-based screening systems are obvious starting points in the search for a general model for predicting invasive plants. Although each system was designed for a specific geographic region, they may function well elsewhere. In fact, the Australian system has been applied successfully in New Zealand and may be applicable elsewhere (Pheloung et al. 1999).

We test here the ability of screening systems originally developed for North America (Reichard and Hamilton 1997), the South African fynbos (Tucker and Richardson 1995) and Australia (Pheloung et al. 1999) to predict invasive plants in the Hawaiian Islands. There are several reasons to expect that these screening systems, particularly the first two, will not accurately predict invaders in the Hawaiian Islands. First, the North American and South African screening systems were developed for predicting invaders in continental regions, rather than for islands. Oceanic islands are often deemed more vulnerable than continents to invasion (Elton 1958; Loope and Mueller-Dombios 1989; Lonsdale 1999). Species capable of invading islands may not be invasive on continents. Furthermore, the Hawaiian Islands have a tropical or sub-tropical climate. The North American and fynbos screening systems were developed for non-tropical environments (mainly temperate climates). Furthermore, characteristics of invaders and the susceptibility of communities to invasion have been proposed to be different among climatic regions (Ramakrishnan 1991; Reichard and Hamilton 1997; Lonsdale 1999). On the other hand, the Australian system was successfully applied to New Zealand (Pheloung et al. 1999), and Australia includes a wide range of climates from desert to tropical rainforest. Nevertheless, the Australian system has not been widely tested outside Australia or New Zealand. If one or more of the regional screening system were to prove highly predictive with the Hawaiian non-indigenous flora, this outcome would support the contention that a single, general screening system could be useful for evaluating risks of species introduction across many regions (Pheloung et al. 1999). Such a system could then be modified and adopted elsewhere with little development cost.

Methods

Invasive species data set

Invasive plants in the Hawaiian Islands were identified based on lists developed by the Cooperative Parks Study Unit at the University of Hawaii (http://www.botany.hawaii.edu/faculty/cw_smith/aliens.htm), and the Hawaii Ecosystems at Risk Project (http://www.hear.org/). From among the alien species proposed as pests by these conservation groups, we selected angiosperms that are invasive in natural or semi-natural habitats and are considered priorities for control and eradication, or both, by federal land managers. Using these criteria, we obtained an invasive species data set consisting of 54 invasive species in the Hawaiian Islands (Appendix 1). The data set includes species in all stages of invasion, from those that have small but rapidly expanding populations to those that have already become widespread in natural areas.

Non-indigenous, non-invasive species data set

We assembled another list of non-indigenous, but currently non-invasive, plant species in the Hawaiian flora by randomly identifying 57 angiosperm species (Appendix 2) from among the species described in Neal (1965). Neal (1965) emphasizes species commonly grown as ornamentals, crops or forage in fields, gardens, and parks in the Hawaiian Islands. We confirmed that each randomly chosen species was non-invasive (not spreading in natural areas) by consulting with local land mangers. All species in our non-indigenous, non-invasive species data set have occurred in the Hawaiian Islands for at least 35 years, and most have been present for more than 70 years (Neal 1965).

Modifying screening systems for the Hawaiian Islands

Only minor modifications were made to the three screening systems before their application to the

Hawaiian flora. For the decision tree in the North American screening system (Reichard and Hamilton 1997), all screenings began with the same question. Depending on the answers ('yes' or 'no') to the first and subsequent questions, we were led to different branches of the decision tree and different questions. Three final outcomes were possible: 'accept', 'reject' or 'further analysis'. Two questions on the North America decision tree were modified for the Hawaiian flora. 1) 'Is it in a family or genus with other species already strongly invasive in North America?' was modified to, 'Is it in a family or genus with other species strongly invasive in Pacific Islands?' and 2) 'Is it native to parts of North America other than the region of the proposed introduction' was changed to, 'Is it native to Pacific Islands but not the Hawaiian Islands?' The other questions in this system do not inquire about specific regions and were not modified. The entire decision tree is outlined in Reichard and Hamilton (1997).

The South African fynbos screening system (Tucker and Richardson 1995) consists of a linear series of five modules, each of which contained multiple questions. Depending on the answers to questions within each module, a species is either classified as 'low risk', or the procedure deferred to the questions in the next module. If a species advances through all modules without being classified as 'low risk', the species is considered 'high risk'. To compare the three screening systems, we considered the 'low risk' and 'high risk' to be comparable to 'accept' and 'reject' in the other screening systems. The fynbos screening system was modified for the Hawaiian flora by deleting questions relating to fire regime and adaptation to fire (the last module as well as the first two questions of the first module). Although fire is important in the fynbos environment, natural fires play a comparatively small role in structuring most native communities in the Hawaiian Islands. Some questions referred specifically to the fynbos. For example 'Equivalent dispersal vector in the fynbos?' For these questions, 'Hawaiian Islands' was substituted for 'fynbos'.

The Australian screening system (Pheloung et al. 1999; available on line at http://www.aqis.gov.au/docs/plpolicy/wrmanu.htm) consists of 49 questions, not all of which need to be answered. Based on answers to the questions, a species is assigned a numeric score. A score of zero or less receives an 'accept' recommendation. A species scoring in the 1–6 range requires further evaluation, and a species scoring greater than 6 is given a 'reject' recommendation. We modified the Australian screening system by changing the question 'Native or naturalized in regions with extended dry seasons?' to 'Native or naturalized in regions with tropical or sub-tropical climates?', a question that more closely reflects the environment of Hawaiian Islands. In addition, for questions referring specifically to Australia, we substituted 'Hawaiian Islands'. Finally, for the question relating to soil conditions, we followed a modification made for New Zealand, changing 'Grows on infertile soils?' to 'Grows on a wide range of soil conditions?' (Pheloung et al. 1999).

Researching species

Wherever possible, we answered the questions posed by the screening systems from the primary literature through database searches using Biological Abstracts (BIOSIS, Philadelphia, Pennsylvania), Agricola (National Agricultural Library, Beltsville, Maryland) and Uncover (The Uncover Company, Denver, Colorado). For many species, primary literature is not available, and we were forced to obtain information from other sources. We consulted floras for regions in which each species is native. Many aggressive invaders of natural areas in the Hawaiian Islands were introduced for horticulture (Daehler and Carino 1999), as is true elsewhere (Cronk and Fuller 1995; Gordon and Thomas 1997). Information was obtained through horticultural manuals, books, edited conference proceedings, the World Wide Web, and the Bishop Museum (Honolulu, Hawaii). Finally, some information was obtained through personal communication with faculty of the University of Hawaii Department of Horticulture and through interviews with plant nursery workers. If a plant is grown horticulturally, horticulturists and plant nursery workers often have first hand experience that can answer questions posed by the screening systems. To minimize bias, we generally did not inform these sources of our reason for requesting information. Information obtained in this fashion appears comparable in consistency to published information. To avoid tautology in testing the screening systems for the Hawaiian Islands, we were careful not to use information derived from the species' performance in the Hawaiian Islands. In a few cases where we found a range of information or opposing but putatively reliable answers, we used the answer that increased the chance of a species being rejected. We applied this criterion equally to species in the invader and non-invader data sets. We reasoned that it would be less costly to erroneously reject a non-invasive species than to admit a future invader (Pheloung et al. 1999).

Results

North America screening system

None of the invasive species in the Hawaiian flora were accepted using the North American screening system, although 82% were rejected (Table 1). Among the non-invaders, a few were rejected but the vast majority were accepted (Table 1). Rates of correct classification for invaders of the Hawaiian Islands are comparable to those for the region for which the screening system was constructed (Table 1). Classification of non-invaders is significantly more accurate for the Hawaiian Islands than for North America ($\chi^2 = 34.6$, $P < 0.001$). A larger fraction of Reichard and Hamilton's (1997) non-invaders are invasive elsewhere or belong to genera invasive elsewhere, leading to higher rejection rates of non-invaders in North America.

South African fynbos screening system

Almost 40% of the invaders in the Hawaiian Islands are accepted using the South African fynbos screening system, and about one-third of non-invaders are rejected (Table 2). The fynbos system proved substantially more predictive in the fynbos (Table 2). Tucker and Richardson (1995) did not explicitly screen non-invaders in the fynbos flora, so a comparison with results from non-invaders in the Hawaiian Islands was not possible.

Australian screening system

Scores for species in our data sets ranged from −9 to 31 (Figure 1). After we conducted our analyses, we discovered that 13 species from our invaders data set and one species in our non-invaders data set had also been used to calibrate the Australian screening system. Our modifications to the questions and the assembly of more recent information than that available to Pheloung et al. (1999) probably led to slightly different scores for these species in Hawaii. Nevertheless, we present our results after excluding these species to eliminate any possible circularity in evaluating the system in the Hawaiian flora (Table 3). More than 90% of the invasive species in the Hawaiian Islands are rejected using the Australian system, and none are accepted (Table 3). For comparison to the Hawaiian Islands, we also summarize results for invaders of natural areas in New Zealand, using species listed in Owen (1997) for which scores are available (P. Williams, personal communication). The rates of rejection for invaders of natural areas in New Zealand are likewise greater

Table 1. Application of the North American screening system (Reichard and Hamilton 1997) to the Hawaiian Islands and comparison to its predictive ability for North America.

	Accept	Further study	Reject
Hawaii			
Invaders	0	5 (18%)	23 (82%)
Non-invaders	23 (79%)	3 (10%)	3 (10%)
North America[a]			
Invaders	4 (2%)	27 (13%)	174 (85%)
Non-invaders	40 (46%)	16 (18%)	31 (26%)

[a]From Reichard and Hamilton (1997).

Table 2. Application of the South African fynbos screening system (Tucker and Richardson 1995) to the Hawaiian Islands and comparison to its predictive ability for the fynbos.

	Accept	Reject
Hawaii		
Invaders	11 (39%)	17 (61%)
Non-invaders	19 (66%)	10 (34%)
Fynbos[a]		
Invaders	3 (21%)	11 (79%)

[a]From Tucker and Richardson (1995).

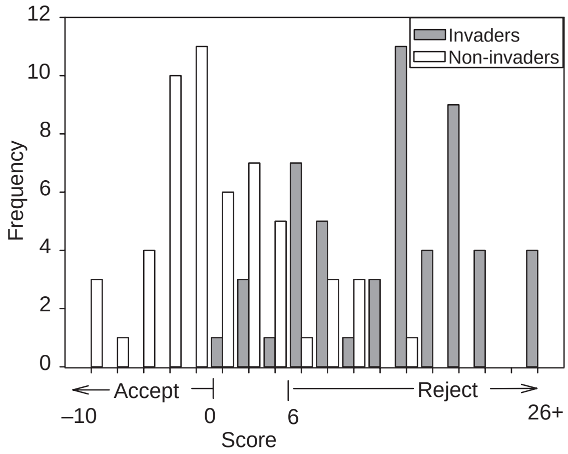

Figure 1. Frequency distributions of scores for invasive and non-invasive plants in the Hawaiian Islands, as determined by the Australian screening system (Pheloung et al. 1999).

Table 3. Application of the Pheloung et al. (1999) screening system to the Hawaiian Islands and comparison of its predictive ability for natural area invaders in New Zealand.

	Accept	Further study	Reject
Hawaii			
Invaders	0	3 (7%)	38 (90%)
Invaders (all)[a]	0	5 (9%)	49 (91%)
Non-invaders	30 (54%)	18 (32%)	8 (14%)
Non-invaders (all)[a]	31 (54%)	18 (32%)	8 (14%)
New Zealand			
Invaders[b]	1 (2%)	3 (6%)	47 (92%)
Non-weeds[c]	16 (64%)	7 (28%)	2 (8%)

[a]Includes species that were used to calibrate the Australian system in Australia.
[b]Natural area invaders listed in Owens (1997) for which scores were available from New Zealand (P. Williams, personal communication).
[c]From Williams (1996).

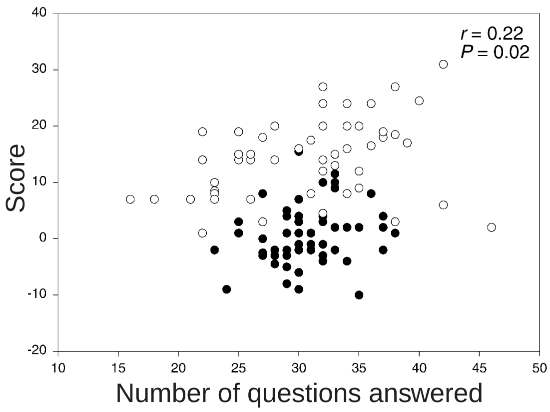

Figure 2. Scores obtained from invasive (empty circles) and non-invasive plants (solid circles) in Hawaii *versus* the number of questions answered for each species using the Australian screening system (Pheloung et al. 1999). The number of questions answered for each species was dependent on the amount of information available on each species.

than 90% (Table 3). Among non-invaders, over half are accepted but a large fraction are classified in the 'further study' category (Table 3). Similar results are obtained for non-weeds in New Zealand (Table 3).

A species can be scored using the Australian system after answering a minimum of 10 questions, provided that some questions have been answered in each subject area (Pheloung et al. 1999). While this feature is convenient, it could lead to bias if species for which more questions are answered have lower (or higher) scores. Although we found a weak positive correlation between the number of questions answered and the score (Figure 2), the statistical significance of this correlation was due to a single outlier (score of 31 with 42 questions answered). Without this outlier the correlation is non-significant ($r = 0.18$, $P = 0.07$). In any case, there is no clear relationship between score and number of questions answered, at least within the range of 15–45 questions observed for the Hawaiian data sets (Figure 2).

Discussion

For the Hawaiian Islands, we obtained the most promising results with the North American and Australian screening systems. Both systems flag all of the invasive species in our data set, and over 80% of the invaders in natural area were rejected outright. These systems seem to require little modification for use in a new region, such as the Hawaiian Islands. The South African fynbos screening system (Tucker and Richardson 1995) did not perform well with the Hawaiian flora. The fynbos system is the most specialized of the three systems, as it was designed for a specific ecosystem, and it may require extensive modification for use in other environments.

Some studies have used phylogenetically independent contrasts to identify traits associated with invaders (Crawley et al. 1996), but this protocol is not usually relevant in assessing screening systems such as those evaluated here. Screening systems designed for detecting invasive plants do not require identification of the trait(s) that allow species to invade; neither do they necessarily explain why a species is invasive. Instead, the goal of these three systems is to predict the likely behavior of an immigrant species to a region, based on any relevant information, including phylogeny. For example, the Australian system asks whether a species is a member of the Poaceae; this information contributes to the overall decision. The species in our data sets represent a wide diversity of functional groups and plant families, ensuring that our results for the Hawaiian flora are not based on a narrow group of closely related species.

Our data set for the Hawaiian flora consists only of species that invade natural areas, i.e., a small fraction of the alien flora of the Hawaiian Islands. Had we included less aggressive invaders in our data set, the prediction success rate may not have been as high. The Australian system has been employed with the New Zealand flora, using a variety of types of non-indigenous weeds, from minor weeds to major economic pests. Scores from the

Australian system generally correlate with the degree of weediness as judged by weed specialists, conservationists and botanists (Pheloung et al. 1999). We expect that the same relationship would be found in the Hawaiian flora, had we screened minor invaders. Some probably would be rejected but many would have lower scores, leading to a recommendation for further study. We focused here on aggressive invaders because a successful screening system at the very least must deny entry consistently to the most devastating invaders of natural areas. In this respect, the Australia and North America systems were successful. Although invaders of natural areas are now recognized as a serious problem in most regions (Cronk and Fuller 1995), few regions have objective methods in place for evaluating species proposed for introductions (Ruesink et al. 1995). Under these circumstances, a screening system that can detect aggressive plant pests is urgently needed; the system's reliability in screening out minor invaders is less important. Although we focused on invaders of natural areas, we expect the Australian screening system would also be successful at identifying noxious agricultural weeds in the Hawaiian Islands because the system was designed for predicting all manner of non-indigenous plant pests.

Both the North American system and the Australian system ask whether the species being screened is invasive elsewhere. A positive answer increases the likelihood of rejection. This question may seem tautological, yet practically speaking it is an important question because past invasion success appears to be one of the best predictors of future invasion elsewhere (Daehler and Strong 1993, 1994; Reichard and Hamilton 1997; Horvitz et al. 1998). Removing the question 'Environmental weed elsewhere?' from the Australian screening system lowers the scores of those species that are invasive elsewhere by 1–4 points, depending on the climatic distribution of the species. In most cases this change would not lead to a different decision for the Hawaiian invaders. Likewise, the North American model has also produced results nearly as well without the question about past invasion success (Reichard and Hamilton 1997, p 197). Nevertheless, we do not recommend removing questions about past invasion success from screening systems simply to address a largely academic debate about the meaning of prediction. Few invasive species are likely to have been introduced throughout their entire potential range; therefore, rejecting a species on the basis of having invaded elsewhere is likely to prevent future invasions.

If past invasion record is a good predictor of future invasiveness, we asked whether that criterion alone could be used to predict invasiveness just as effectively as the screening systems. Among the Hawaiian invaders, 33 out of 54 were recognized as invaders of natural or semi-natural habitats outside the Hawaiian Islands. Thus, only 61% of invaders would have been predicted based on their history as an invader, relative to 82% and 93% prediction rates obtained by using the entire North American and Australian screening systems, respectively.

We spent approximately six hours per species actively seeking answers for the screening systems. Because many of the sources we searched contain answers to questions within two or more screening systems, it is difficult to estimate how much time was spend gathering data for each screening system. More time was usually spent attempting to answer questions for the Australian screening system, simply because that system has the most questions. Pheloung et al. (1999) suggest that answering larger numbers of questions will likely reduce the number of 'further study' outcomes, leading to decisions to reject or accept. There could be a tendency to have more 'further study' classifications when fewer than 20 questions are answered, but with more than 20 questions answered, there was not an obvious decline in the 'further study' classifications when larger numbers of questions were answered (Figure 2).

Implications of implementing a screening system

Few introduced species become invasive (Williamson 1996). Because most species being screened are unlikely to be invasive, even a high success rate in correctly identifying non-invaders will lead to rejection of a large absolute number of non-invaders (Smith et al. 1999). Unnecessarily rejecting a proposed introduction could be costly if it results in missed economic opportunities. Most plant introductions probably have little or no economic value, even when the original purpose of the introduction was for economic benefits (Lonsdale 1994; Smith et al. 1999). None of the rejected non-invaders in the Hawaiian data set are economically important species in Hawaii. Some economically valuable non-invaders that are rejected by a screening system can probably be substituted with native species, which are often overlooked but may yield similar economic benefits (Butterfield and Fisher 1994;

Haggar et al. 1998; Leakey and Simons 1998). For rejected introductions purported to have high economic value, additional cost–benefit analyses may be necessary (Pheloung et al. 1999).

The difficulties of weighing the costs and benefits of introductions are legion (Daehler and Gordon 1997; Ewel et al. 1999). The direct monetary costs of controlling invasive plants are high in Hawaii and elsewhere (OTA 1993). Yet it is difficult to assign monetary costs to changes in ecosystem services associated with plant invasions. In cases in which estimates have been attempted they can be surprisingly high (e.g. vanWilgen et al. 1996). While some non-invasive species will inevitably be rejected even with a highly accurate screening system (Smith et al. 1999), a much larger number of non-invasive species (and whatever economic benefits they bring) would be accepted for introduction; at the same time most costly invaders could be excluded.

Prospects for a general screening system to identify invasive plants

The respectable performance of the North American screening system (Reichard and Hamilton 1997) and even better performance by the Australian screening system (Pheloung et al. 1999) with the Hawaiian flora suggests that these systems can be modified for international use. Overall, the Australian system seems to have several advantages. First, the Australian system can be used with herbaceous species while the other two systems are restricted, by design, to woody species. Second, the Australian system also had the highest rate of correct identification of invasive plants. Finally, unlike the North America and South African fynbos systems, the Australian system can be employed to evaluate species even if answers to some questions are unknown. Based on our results for the Hawaiian Islands, as well as previous results for New Zealand (Pheloung et al. 1999), the Australian system appears to be a promising template for building a globally applicable screening system. We predict that adoption of the Australia screening system in assessing the entry of non-indigenous species into the Hawaiian Islands and elsewhere would substantially reduce introductions of invasive plants.

Acknowledgements

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Appendix 1. Species known to be invasive in natural areas in the Hawaiian Islands, and their evaluation using three screening systems. Only woody species were evaluated with the Reichard and Hamilton, and Tucker and Richardson systems. Numbers in parentheses in the Tucker and Richardson column indicates the module number (as per Tucker and Richardson 1995) which led to the prediction of low risk.

Species	Pheloung	Pheloung score	Reichard and Hamilton	Tucker and Richardson
Acacia mearnsii	Reject	15	Reject	Accept (3)
Andropogon virginicus[a]	Reject	8.5		
Brachiaria mutica[a]	Reject	14		
Caesalpinia decapetala	Reject	13		
Casuarina equisetifolia	Reject	15	Reject	Accept (3)
C. glauca	Reject	8	Reject	Accept (3)
Cenchrus ciliaris[a]	Reject	12		
Citharexylum caudatum	Evaluate	3	Evaluate	Reject
Clidemia hirta	Reject	19	Reject	Reject
Coccinia grandis[a]	Reject	18		
Cortaderia jubata[a]	Reject	17		
Cryptostegia grandiflora[a]	Reject	24		
Erigeron karvinskinaus	Reject	14		
Fraxinus uhdei	Reject	8	Reject	Accept (3)

Appendix 1. Continued.

Species	Pheloung	Pheloung score	Reichard and Hamilton	Tucker and Richardson
Grevillea banksii	Reject	7	Evaluate	Accept (3)
Hedychium gardnerianum	Reject	27		
Lantana camara[a]	Reject	31	Reject	Reject
Leptospermum scoparium	Reject	14	Reject	Reject
Leucaena leucocephala[a]	Evaluate	3	Reject	Accept (3)
Lonicera japonica	Reject	19	Reject	Reject
Melaleuca quinquenirvia	Reject	20	Reject	Reject
Melia azedarach	Reject	14	Reject	Accept (3)
Melinis minutiflora	Reject	7		
Merremia tuberosa	Reject	14		
Miconia calvescens	Reject	18	Reject	Reject
Myrica faya	Reject	6	Evaluate	Reject
Nicotiana glauca	Reject	20	Reject	Accept (3)
Olea europea[a]	Evaluate	2	Reject	Accept (1)
Panicum maximum[a]	Reject	14		
Paspalum conjugatum	Reject	19		
Passiflora mollissima	Reject	16.5		
Pennisetum clandestinum[a]	Reject	12		
P. setaceum	Reject	18.5		
Phormium tenax	Evaluate	4.5		
Pithecellobium dulce	Reject	17	Reject	Reject
Pittospororum undulatum	Reject	24	Reject	Reject
Polygonum chilense	Reject	19		
Psidium cattleianum	Reject	27	Reject	Reject
P. guajava	Reject	20	Reject	Reject
Pueraria lobata	Reject	24		
Rhizophora mangle	Reject	9	Reject	Accept (2)
Rubus argutus	Reject	13.5		
Schefflera actinophylla	Reject	8	Reject	Reject
Schinus terebinthifolius	Reject	19	Reject	Reject
Senecio madagascariensis[a]	Reject	15		
S. mikanioides	Reject	17.5		
Setaria palmifolia	Reject	7		
Spathodea campanulata	Reject	7	Reject	Reject
Syzygium jambos	Reject	16		
Tibouchina herbacea	Reject	7		
T. urvilleana	Evaluate	1	Evaluate	Accept (3)
Trema orientalis	Reject	7	Evaluate	Reject
Ulex europaeus[a]	Reject	24.5	Reject	Reject
Verbascum thapsus	Reject	13		

[a] Species used to calibrate the Australian screening system in Australia.

Appendix 2. Plant species that have not invaded natural areas (non-invaders) in the Hawaiian Islands, and their evaluation using three screening systems. Only woody species were evaluated with the Reichard and Hamilton, and Tucker and Richardson systems. Number in parentheses in the Tucker and Richardson column indicates the module number (as given in Tucker and Richardson 1995) which led to the prediction of low risk.

Species	Pheloung	Pheloung score	Reichard and Hamilton	Tucker and Richardson
Abelia chinensis[a]	Accept	−14		
Acacia catechu	Reject	11.5	Evaluate	Accept (3)

Appendix 2. Continued.

Species	Pheloung	Pheloung score	Reichard and Hamilton	Tucker and Richardson
Acokanthera spectablis	Accept	−6	Accept	Reject
Adenium obesum	Accept	−3		
Aechmea fulgens	Accept	−1		
Allium cepa	Evaluate	2		
Aloe barbadensis	Evaluate	4		
Alstroemeria pulchella	Evaluate	3		
Aphelandra aurantiaca	Accept	−3		
Averrhoa carambola	Accept	−3	Accept	Reject
Barringtonia asiatica	Accept	−2	Accept	Accept (3)
Bombax malaarica	Accept	−2	Accept	Accept (3)
Calathea illustris	Accept	−2		
Carica quercifolia	Accept	−2		
Castanea crenata	Accept	−2	Accept	Accept (1)
Chrysophyllum pruniferum	Accept	−5	Accept	Reject
Citrus aurantifolia	Evaluate	1	Accept	Reject
Dendrobium superbum	Accept	−9		
Diascia barberae	Accept	−1		
Dioscorea batatas	Evaluate	2		
Elaeagnus multiflora	Reject	10	Accept	Accept (2)
Eucharis grandiflora	Accept	−10		
Eustrephus latifolia	Accept	−3		
Ficus pumila	Reject	10	Reject	Reject
Finschia chloroxantha	Accept	−5	Accept	Reject
Flemingia strobilifera	Reject	8	Reject	Accept (3)
Fortunella japonica	Accept	−8	Accept	Reject
Gardenia thunbergia	Accept	−3	Accept	Accept (3)
Gliricidium sepium	Evaluate	4	Reject	Accept (3)
Haemathus multiflora	Evaluate	1		
Hakea saligna	Evaluate	4	Evaluate	Accept (3)
Hebe × *andersonii*	Accept	−9	Accept	Accept (3)
Heliconia mariae	Evaluate	4		
Hemerocallis flava	Accept	−2.5		
Hernandia sonora	Accept	−3	Accept	Accept (2)
Hibiscus sabdariffa	Evaluate	3		
H. syriacus	Accept	−4.5	Accept	Accept (1)
Kochia scoparia	Reject	15.5		
Latania loddigesii	Accept	−4	Accept	Accept (3)
Ligustrm vulgare	Reject	8	Evaluate	Accept (1)
Linum grandiflorum	Evaluate	1		
Malpighia cocciegera	Accept	−4	Accept	Reject
Maranta arundinacea	Evaluate	3		
Montezuma speciosissima	Accept	−2	Accept	Accept (3)
Nandina domestica	Accept	−2	Accept	Reject
Pandorea jasminoides	Evaluate	0		
Parkia javanica	Evaluate	1	Accept	Accept (3)
Peperomia scandens	Evaluate	1		
Piper ornatum	Accept	−2	Accept	Accept (3)
Sandoricum koetjape	Accept	−3	Accept	Reject
Sesamum indicum	Reject	9		
Solanum mammosum	Evaluate	5		
Stokesia laevis	Evaluate	2		
Tagetes patula	Evaluate	2		
Terminalia chebula	Accept	−2	Accept	Accept (3)

Appendix 2. Continued.

Species	Pheloung	Pheloung score	Reichard and Hamilton	Tucker and Richardson
Trachelospermum jasminoides	Accept	−1	Accept	Accept (3)
Victoria amazonia	Reject	7		

[a]Species used to calibrate the Australian screening system in Australia.

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