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Predicting Invasive Plants in Florida Using the Australian Weed Risk Assessment

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Screening tools that effectively predict which nonnative species are likely to become invasive are necessary because of the disproportionate ecological and economic costs associated with invaders. We tested the effectiveness of the Australian Weed Risk Assessment system (WRA) in distinguishing plant species that are major invaders, minor invaders, and noninvaders in Florida. The test included 158 annuals and perennials in six growth forms from 52 families in 27 orders. The WRA with a secondary screen met all hypothesized accuracy levels: it correctly rejected 92% of test species that have been documented to be invasive in Florida and correctly accepted 73% of the noninvaders. The incorrect rejection of noninvaders was 8% with the remaining 19% of noninvaders falling into the "evaluate further" outcome. Only 10% of the 158 species required further evaluation. Invaders of natural areas and agricultural systems were identified with equal accuracy. Receiver operating characteristic analysis demonstrated high separation of invaders from noninvaders. The degree to which the WRA is precautionary may be adjusted by altering the cutoff scores that define the "accept, evaluate further," and "reject" outcomes. This approach could be adopted in Florida as a screening mechanism to reduce importation of new invaders.

Key words: Alien invasive species, nonnative, predictive screening.

Invasive species are widely recognized as causing serious ecological and economic impacts in habitats throughout the world (Mooney et al. 2005). In the United States, they are the second-most critical threat to conservation of biodiversity (Wilcove et al. 1998). Additionally, these species have been estimated to incur annual costs of approximately $120 billion in the United States, of which over $34 billion is specifically attributed to invasive plants (Pimentel et al. 2005). These figures include costs of control programs to reduce the impacts of invasive species and estimates of their economic and ecological damage. In Florida, for example, over $240 million was spent by public agencies between 1980 and 2000 to control invasive plant species in natural areas and waterways (Florida Invasive Species Working Group 2003). Invaders are also costly to agricultural production in Florida, with annual impacts of $179 million incurred by all nonnative taxa (Pest Exclusion Advisory Committee 2001). Although ecological impacts of many invasive plant species in Florida have been documented (Fox et al. 2005; Gordon 1998), economic value of these impacts has rarely been estimated (e.g., Carter-Finn et al. 2006).

Of the vast majority of nonnative species that do not become invasive (Williamson and Fitter 1996), many contribute substantially to important sectors of the U.S. economy. Most plants used in agriculture, forestry, and horticulture in North America have been introduced from other continents (Reichard and White 2001). The horticulture industry is the sixth largest agricultural commodity group in the United States (Johnson 1999) and is the fastest growing sector of agriculture (Hall et al. 2006). Florida's horticultural industry is currently valued at $6.8 billion and is rapidly growing (Hodges and Mulkey 2006). However, the majority of the nonnative plant species invading natural areas in Florida, as in other locations, were initially introduced for horticultural purposes (Gordon and Thomas 1997). Given the potential for conflict between efforts to identify new species for this growing industry and to prevent import of species likely to become invasive, screening tools that could be used to differentiate likely noninvaders from invaders are increasingly necessary (Leung et al. 2002; McNeely et al. 2001; National Invasive Species Council 2001).

Although invasive plant risk screening systems have been developed for some countries (e.g., the Australian WRA; Pheloung et al. 1999; Williams and West 2000), those that

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Interpretive Summary

The significant ecological and economic impacts of invasive species suggest that we need effective approaches to limit their spread. The Australian Weed Risk Assessment (WRA) is currently used within the plant introduction regulations of both Australia and New Zealand to prevent importation of new plant species likely to become invasive, and has been tested in a number of other countries and Hawaii. We conducted the first statewide test of the WRA within the continental United States. Our research suggests that the accuracy of the WRA in differentiating invasive from noninvasive species is similar in Florida to that in Australia and the other tested locations.

Our result suggests that if Florida wished to implement a voluntary or regulatory screening approach for introduction of new species, the WRA could be used. Virtually all likely invaders and the majority of species likely to become naturalized (and potentially to invade) would be identified, with low probability of rejecting species that will not spread beyond cultivation. This result, and studies by researchers in other parts of the world (Gordon et al. 2008), also supports the potential for a full U.S. application. However, any agency responsible for regulation or guidance will need to decide how precautionary the screening system should be given the inherent tradeoffs in prediction error rates between correctly rejecting invasive species vs. incorrectly rejecting noninvasive species. Overall, we are optimistic that Florida and the United States could rely on the WRA as a screening mechanism for reducing the importation of and interstate trade in invasive plant species.

have been refined to target the United States include only a limited group of plant taxa (e.g., woody plants in North America: Reichard and Hamilton 1997; and as modified for Iowa: Widrlechner et al. 2004) or have been limited to tropical islands (e.g., Hawaiian nonindigenous flora screening using a modified version of the Australian WRA; Daehler and Carino 2000; Daehler et al. 2004), or to local areas (e.g., Chicago Botanic Garden; Jefferson et al. 2004). The significant consequences of invasive species (Pimentel et al. 2005) and the potential economic benefits of implementing a screening system (Keller et al. 2007) suggest the utility of expanding the current testing. Despite the recognition that a screening system is needed in Florida (Florida Invasive Species Working Group 2003), this paper describes the first work addressing the goal.

The accuracy and effectiveness of the WRA and other screening systems have been tested by identifying groups of noninvasive and invasive nonnative plants that are currently present within the test area, and comparing the a priori designation of ''noninvasive'' or ''invasive'' with the outcome of ''accept'' or ''reject'' by the screening system. Changing the cutoff points that distinguish the outcomes increases the accuracy of predictions about one a priori category at the expense of accuracy about predictions for other a priori categories (Caley and Kuhnert 2006; Pheloung et al. 1999). Because each species lies at some point along a continuum of invasiveness, many researchers have included species that reproduce outside of cultivation but are not having critical impacts in natural or agricultural systems as ''minor invaders'' or similar designation (Daehler et al. 2004; Kato et al. 2006; Křivánek and Pyšek 2006; Pheloung et al. 1999).

Comparisons of existing screening systems have generally favored the Australian WRA (Daehler and Carino 2000; Křivánek and Pyšek 2006). This WRA has been used for longer, and tested more widely, than any other predictive model for invasive plants (Daehler et al. 2004; Jefferson et al. 2004; Kato et al. 2006; Nishida 2006; Pheloung et al. 1999; Williams and West 2000). The system consists of 49 questions about the history of use and weediness, distribution, climate requirements, biology, and ecology of plant species being proposed for importation (Table 1). Depending on the answer, each question is awarded between -3 and 5 points (most -1 to 1), and the final point total leads to one of three outcomes: *accept* the species for importation (< 1 point), *reject* the species (> 6 points), or hold the species to *evaluate further* its invasive potential (1 to 6 points). Cutoff points were assigned by the WRA developers at levels that would have precluded the introduction of historically serious invaders, limited the rejection of noninvaders to 10%, and limited the species that would require further evaluation to 30% (Pheloung et al. 1999). Testing was conducted on 370 nonnative plant species present in Australia, 81% of which persist outside of cultivation. Of the tested species, fewer than 40% were considered ''serious weeds,'' of either agricultural or natural systems (Pheloung et al. 1999). The cutoffs established to meet the specified accuracy also resulted in rejection or further evaluation required of 85% of the minor invaders included.

The Australian WRA has been incorporated into phytosanitary regulations in both Australia and New Zealand. Any plant species proposed for introduction to either country that has not previously been categorized as ''accept'' or ''reject'' is evaluated prior to import (Williams and West 2000). In Australia, using this system on a total of 2,800 species has resulted in the exclusion of 756 species (27%) from mid-1997 to August 2006, whereas 1,484 species (53%) have been allowed introduction, and 560 species (20%) required further evaluation (B. Riddle, personal communication).

To reduce the proportion of species requiring further evaluation, Daehler et al. (2004) developed a secondary screen, made up of a small subset of WRA questions in a decision tree with different questions depending upon the species' growth form. Three questions for trees address shade tolerance, stand density, dispersal process, and generation time. For herbs and small shrubs, the questions address whether the species is an agricultural weed, its palatability to grazers, and its stand density. Both sets of questions area answered for vines. Running the 24% of their tested species that had WRA scores of 1 to 6 (evaluate

Table 1. Australian Weed Risk Assessment question sheet (modified from Pheloung et al. 1999). Aspects of questions altered to increase specificity to Florida are italicized.

Biogeography/history				
A[a]	1	Domestication/cultivation	1.01	Is the species highly domesticated?
C			1.02	Has the species become naturalized where grown?
C			1.03	Does the species have weedy races?
	2	Climate and distribution	2.01	Species suited to *Florida's USDA climate zones* (0-low; 1-intermediate; 2-high)
C			2.02	Quality of climate match data (0-low; 1-intermediate; 2-high)
C			2.03	Broad climate suitability (environmental versatility)
			2.04	Native or naturalized in habitats *with periodic inundation*
			2.05	Does the species have a history of repeated introductions outside its natural range?
C	3	Weed elsewhere	3.01	Naturalized beyond native range
E			3.02	Garden/amenity/disturbance weed
A			3.03	Weed of agriculture
E			3.04	Environmental weed
			3.05	Congeneric weed
Biology/ecology				
A	4	Undesirable traits	4.01	Produces spines, thorns or burrs
C			4.02	Allelopathic
C			4.03	Parasitic
A			4.04	Unpalatable to grazing animals
C			4.05	Toxic to animals
C			4.06	Host for recognized pests and pathogens
C			4.07	Causes allergies or is otherwise toxic to humans
E			4.08	Creates a fire hazard in natural ecosystems
E			4.09	Is a shade tolerant plant at some stage of its life cycle
E			4.10	Grows on infertile soils (*oligotrophic, limerock, or excessively draining soils)*
E			4.11	Climbing or smothering growth habit
E			4.12	Forms dense thickets
E	5	Plant type	5.01	Aquatic
C			5.02	Grass
E			5.03	Nitrogen fixing woody plant
C			5.04	Geophyte
C	6	Reproduction	6.01	Evidence of substantial reproductive failure in native habitat
C			6.02	Produces viable seed
C			6.03	Hybridizes naturally
C			6.04	Self-compatible or apomictic
C			6.05	Requires specialist pollinators
C			6.06	Reproduction by vegetative fragmentation
C			6.07	Minimum generative time (years)
A	7	Dispersal mechanisms	7.01	Propagules likely to be dispersed unintentionally (plants growing in heavily trafficked areas)
C			7.02	Propagules dispersed intentionally by people
A			7.03	Propagules likely to disperse as a produce contaminant
C			7.04	Propagules adapted to wind dispersal
E			7.05	Propagules water dispersed
E			7.06	Propagules bird dispersed
C			7.07	Propagules dispersed by other animals (externally)
C			7.08	Propagules dispersed by other animals (internally)

Table 1. Continued.

C	8	Persistence attributes	8.01	Prolific seed production
A			8.02	Evidence that a persistent propagule bank is formed (>1 yr)
A			8.03	Well controlled by herbicides
C			8.04	Tolerates, or benefits from, mutilation or cultivation
E			8.05	Effective natural enemies present *in Florida, or east of the continental divide*

[a] Letter codes indicating the question subject area are A, agricultural; E, environmental, and C, combined.

further) through this secondary screen reduced the species in that category to 8%, with both noninvaders (the majority) and minor invaders reclassified to the accept outcome. Tests of this secondary screen in the Czech Republic (Křivánek and Pyšek 2006) and Bonin Islands (Kato et al. 2006) demonstrated similar reductions in the proportion of species in the evaluate further category (27 to 11% and 26 to 10%, respectively) without sacrifices in accuracy.

Our objective was to examine the utility of using a modified version of the Australian WRA to predict invasiveness of nonnative species in Florida. The subtropical to temperate climate range, vast acreage of connected wetlands, and interdigitation of developed, agricultural, and conservation properties in Florida have facilitated the spread of invaders (Ewel 1986; Florida Invasive Species Working Group 2003). In support of the active horticultural industry, Florida's ports received 58% of all shipments of plant material to the United States, comprising 74% of all individual plants transported by air or sea in 2006 (M. Caporaletti, personal communication).

To contribute to the accumulating understanding of accuracy of the WRA, we incorporated a number of methods to reduce potential bias in the Florida test. To identify major invaders and distinguish them from minor invaders, we used independently developed lists of species having destructive impacts in natural and agricultural systems. Other WRA tests have more commonly used expert identification approaches (Daehler and Carino 2000; Daehler et al. 2004; Jefferson et al. 2004; Kato et al. 2006; Křivánek and Pyšek 2006; Nishida 2006; Pheloung et al. 1999; Williams and West 2000) that result in documented variation in how species are categorized (Perrins et al. 1992). We also reduced the potential for bias in the assessment by using a ''blind'' screening process, where the screener neither knew how the species had been classified nor had previous knowledge of most of the species. Additionally, we paired major invader with minor or noninvader species by family or order and growth form. This attention to phylogeny and growth form has been suggested but not incorporated into most of the earlier tests of the WRA (but see Jefferson et al. 2004).

Our work incorporated these potential improvements into a test of the WRA, amended for conditions in Florida and with the secondary screen developed by Daehler et al. (2004). We examined if the outcome (accept or reject) of the WRA matched a priori non-, minor, and major invader categories with similar precision as found for previous tests of the WRA (Gordon et al. 2008). Specifically, based on results from Australia (Pheloung et al. 1999), we hypothesized that the WRA would correctly reject over 90% of test species that are major invaders in Florida. We also hypothesized that the WRA would correctly accept over 75% of species that have never escaped cultivation and require further evaluation for fewer than 15% of the species, based on tests that incorporated the secondary screen (Daehler et al. 2004; Kato et al. 2006; Křivánek and Pyšek 2006). We did not hypothesize precision results for minor invaders, which were predominantly rejected in the precautionary Australian approach (Caley and Kuhnert 2006; Pheloung et al. 1999). Other countries might be more willing to accept minor invaders because they provide economic benefit and may never cause future harm to ecological or economic interests. Instead of hypothesizing precision results for minor invaders, we illustrate the implications of considering minor invaders either as invaders or as noninvaders.

We used receiver operating characteristic (ROC) curve analysis (DeLong et al. 1988) to evaluate the dependence of the WRA on categorization of minor invaders and the consequences of different cutoff points on the accuracy of predictions for the a priori categories. We also tested whether the WRA results varied significantly from the results of two simplified question-based risk assessment approaches: (1) asking only whether the species has been invasive elsewhere and (2) asking four questions derived from the 49 questions of the WRA (Caley and Kuhnert 2006). If either of these approaches results in no significant difference in the conclusions about invasiveness in the suite of plants used, a shorter assessment could be considered.

Materials and Methods

Selection of Species for the Florida Test. The efficacy of the Australian WRA is best tested using a retroactive examination of species that are present in the area of interest and whose (current) degrees of invasiveness are understood. Rather than rely upon expert evaluations of the

Table 2. Numbers of families and orders represented by the species in the a priori categories used in this test of the Australian Weed Risk Assessment.

	Noninvader	Minor invader	Major invader	Total	Overlap across all categories
Family	35	27	36	52	11 (21%)
Order	24	14	25	27	16 (59%)

a priori category in which species are placed, we identified the species to use in our test based on their existing status in plant lists that were derived independently of this investigation. These lists included the University of Florida Institute of Food and Agricultural Sciences (IFAS) Assessment of the Status of Non-native Plants in Florida's Natural Areas (hereafter "IFAS Assessment"; Fox et al. 2005), the Florida Department of Agricultural and Consumer Services Noxious Weed List (FDACS 2007), and summaries of the worst weeds identified in Florida's agricultural systems developed by the Southern Weed Science Society over a 15-yr period (SWSS 1990 to 2005). Although expert opinion is incorporated into these processes, these lists were established for purposes independent of the research conducted here, and incorporate some regulatory and economic criteria.

The IFAS Assessment is a criteria-driven system that was developed to provide an objective, science-based means of developing invasive species rankings. The assessment focuses on nonnative species already present in Florida, using literature and multiple, documented expert observations to consistently identify the current distribution and ecological impact, potential for spread, difficulty of management, and economic value (Fox et al. 2005).

For the major-invader category (analogous to serious or major pests or weeds or simply, invaders in other tests), we selected 62 species documented to invade with detrimental impacts to natural or agricultural areas in Florida. Twenty-nine species were identified as invaders in Florida's natural areas with "not recommended for use" conclusions from the IFAS Assessment system used in Florida (Fox et al. 2005); 26 were identified as common invaders of Florida's agricultural systems (SWSS 1990 to 2005); and seven species were identified in these sources as major invaders in both systems. Seventeen of the major invader species were also on Florida's Noxious Weed List (FDACS 2007).

Agricultural invaders were selected from those that ranked cumulatively highest in periodic "10 most commonly encountered" and "10 most troublesome" weed lists for Florida, sorted by 22 commodity or habitat categories (e.g., specific row crops, forages, turf, ornamentals, forestry, rights-of-way, etc.) (SWSS 1990 to 2005). These expert opinion lists were produced by university Extension faculty familiar with regional commodities and their associated weed problems and include priority weeds identified per commodity several times over the 15-yr span of these data. Species were excluded if no scientific name could be found for the common name provided or if they were native to Florida. Results for these species were compared to those for the natural area invaders to examine whether the WRA works equivalently for invaders of these two systems.

Equal numbers (48) of minor invaders and noninvaders were included in the study. Minor invaders were selected from species recorded as present outside of cultivation in one or more counties in Florida (Wunderlin and Hansen 2003, 2004) but have IFAS Assessment conclusions of "may be recommended for use" (Fox et al. 2005) and are not listed as common agricultural invaders (SWSS 1990 to 2005). This group includes the minor weeds or pests or naturalized species of other studies, but our species identification methods again differed. In most other tests of the WRA, minor invaders were identified by experts as "less harmful" than the species they identified as major invaders. In our approach, minor invaders were species that had been identified by a specific process as reproducing beyond cultivation but not adversely affecting natural or agricultural systems in Florida as of 2006. This definition is most similar to the "naturalized" category used in the Czech Republic test of the WRA (Křivánek and Pyšek 2006).

Noninvaders were selected from species that have not been recorded outside of cultivation in any flora of Florida. These species are analogous to the "not escaped, nonpest, nonweed," and "casual" categories of earlier WRA tests. Both noninvaders and minor invaders had to have been documented in Florida for over 50 yr because more recently introduced species might have not had sufficient time to escape and establish (Hobbs and Humphries 1995; Mack 1996). We excluded any species that were used to develop the original Australian WRA (Pheloung et al. 1999) or the secondary screen (Daehler et al. 2004).

After major invaders were identified, they were paired with a noninvader or minor invader species in the same family (or order, if family matches were not available) (Table 2) and with the same growth form and life history (Table 3) to the extent possible. Our intent was to reduce the potential for bias in the a priori categories of invasiveness (i.e., major invaders in families such as the Poaceae and Asteraceae, and noninvaders in completely different families or overrepresentation of particular growth forms within one a priori group relative to the others).

Because we had difficulty identifying nonnative aquatic species that had been in Florida for over 50 yr and that are

Table 3. Number of species representing various growth forms and life histories within noninvader (n = 48), minor invader (n = 48), and major invader (n = 62) a priori categories.

	Noninvader	Minor invader	Major invader	Total
Growth form				
Forb/herbaceous	12	18	23	53
Graminoid[a]	3	8	8	19
Shrub	10	5	8	23
Subshrub	1	2	1	4
Vine	7	8	9	24
Tree	15	7	13	35
Life history				
Annual or biennial	5	15	21	41
Perennial	43	33	41	117

[a] All bamboos are included as graminoids.

not considered invasive, this group is underrepresented in the dataset. The authors of the WRA clearly concluded that this life form has a high probability of becoming invasive: aquatic plants receive five points simply on the basis of that characteristic. So, although we know that aquatic species are likely to be rejected, only one such species was included in this test (*Myriophyllum spicatum* L.). A total of 158 species were examined for this project (Appendix A).

Application of the Australian WRA. We interpreted the 49 WRA questions (Table 1) using the information provided on the website for the Australian test (Biosecurity Australia 2007). Consistent with the other tests of the WRA (Daehler and Carino 2000; Daehler et al. 2004; Jefferson et al. 2004; Kato et al. 2006; Křivánek and Pyšek 2006; Pheloung et al. 1999), questions were modified as necessary to reflect Florida's environment (see italicized questions in Table 1). Question 2.01 was changed from "Species suited to Australian climates?" to "Species suited to Florida's USDA hardiness zones?" Question 2.04 was modified from "Native or naturalized in regions with extended dry periods?" to "Native or naturalized in habitats with periodic inundation?" because this is the more common condition in many of Florida's habitats. We changed question 8.05 from "Effective natural enemies present in Australia?" to "Effective natural enemies present in Florida, or east of the Continental Divide?" Although question 4.10 "Grows on infertile soils?" has been modified in other tests, Florida soils are largely oligotrophic so we did not modify this question.

Not explicitly stated in other tests, but potentially similarly addressed, we answered question 1.01, "Is the species highly domesticated?", in two steps. The intent of the question is to identify whether domestication has reduced the invasiveness of a species. A "yes" response is worth -3 points and a "no" response, 0 points. Thus, we asked first whether the species has been cultivated and subjected to substantial human selection for at least 20 generations (or fewer, if the selection has resulted in a handicap that would limit the species' survival in the wild), and then whether the traits selected for are likely to have made the species more or less weedy than its original form (D. A. Onderdonk, unpublished data). This clarification was necessary because horticultural selection can result in increased invasive potential (e.g., horticultural selection for increased numbers of fruit in *Ardisia crenata* Sims; Kitajima et al. 2006). As a result, only those species for which domestication had likely decreased invasive traits received a "yes" response. If invasive potential was unchanged or increased the response was "no."

Rather than use a climate-matching program for questions 2.01 and 2.02, we followed the alternate WRA guidelines and used default scores when evaluating whether a species is suited to local climate and the reliability of the climate match. Because these scores weight the scores for 'yes' answers to questions 3.01 to 3.05 (whether the species is a weed elsewhere), this approach resulted in the maximum scores for those questions. We found no indication that this approach resulted in a uniformly higher bias in Florida scores compared to those found by other authors (Gordon et al. 2008).

The WRA requires a minimum of two answers in the biogeography section, two in the undesirable traits section, and six in the biology/ecology sections (Pheloung et al. 1999; Table 1). We answered the WRA questions using all available sources, including invasive species references and websites for different regions of the world, horticultural references, the USDA PLANTS database (USDA, NRCS 2007), floras, and the primary literature. No data about the invasiveness of the species within Florida were used.

Bias in tests of the WRA may be reduced if the assessor is unfamiliar with invasive plants in the area of interest (W. M. Lonsdale, personal communication). To our knowledge, this potential source of bias has not been addressed in previous studies. As a result, the Florida assessments were conducted by a trained biologist (D.A.O.) who was not familiar with the nonnative flora of Florida, had no previous experience with invasive plants, and did not know the a priori categorization of the species until all assessments were complete.

Data Analysis. Chi-square analyses were used to evaluate whether model results met our hypothesized accuracy levels for the accept, reject, and evaluate further outcomes and whether the abridged, one-question, or four-question (Caley and Kuhnert 2006) approaches were as accurate as the full WRA. We used a *t* test to determine whether the scores varied for agricultural vs. natural area invaders because of insufficient sample size for a chi-square analysis.

We used ROC curve analysis (DeLong et al. 1988) to measure the ability of our results to discriminate between invaders and noninvaders, and to demonstrate the tradeoffs between correct rejection of invaders and incorrect rejection of noninvaders at different cutoff levels (Caley and Kuhnert 2006). Raising the cutoff score allows more noninvaders to be correctly accepted, but it also means that more invaders would be incorrectly accepted. Conversely, lowering the cutoff point would allow more invaders to be correctly rejected, but it would mean that more noninvaders would be incorrectly rejected. ROC curve analysis requires two a priori categories, necessitating the reduction of the three categories of invasiveness to two. Whether minor and major invaders are grouped within the invader category and distinguished from noninvaders (e.g., Caley and Kuhnert 2006), or whether minor invaders are grouped with noninvaders, because the former are clearly distinct from harmfully invasive species, depends on perspective and would likely be addressed differently under different regulatory contexts. As a result, we constructed the ROC curves both ways for the Florida data and examined the resulting differences in accuracy. We compared the areas under our two curves following Zhang and Pepe (2005).

An ROC curve is formed by plotting the proportion of true positives (here, rejected invaders) against the proportion of false positives (rejected noninvaders) across the range of cutoff points on an indicator scale (the WRA score). Cases above the cutoff are assigned one outcome (reject), and cases below the cutoff are assigned another (accept). The area under the ROC curve represents the probability that a randomly chosen positive case (invader) will have a higher score than a randomly chosen negative case (noninvader) (DeLong et al. 1988). Therefore, the closer the area under the curve is to 1, the better the screening tool's ability to differentiate between the two groups. If the area under the curve is 0.5, the tool allows no discrimination between the two groups (DeLong et al. 1988).

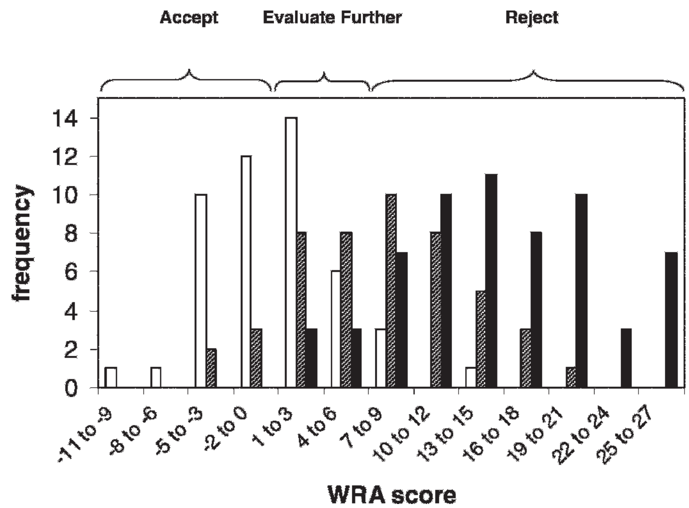

Figure 1. Frequency of weed risk assessment scores using 158 nonnative species in Florida. White bars indicate a priori noninvaders; hatched bars, a priori minor invaders; black bars, a priori major invaders. The outcomes indicated at the top of the graph are based on the Weed Risk Assessment score without application of the secondary screen.

Results

We were able to address the minimum number of required questions for all 158 species to complete the assessment. We answered an average of 35 (range 25 to 44) of the 49 WRA questions for each species (including the three questions that are used only to determine scores of other questions). The scores of species categorized a priori as noninvaders ranged from -11 to 13 (mean $= 0.6 \pm 4.1$ SD), that of minor invaders from -5 to 20 (mean $= 7.3 \pm 5.7$ SD), and major invaders, from 2 to 27 (mean $= 14.9 \pm 6.5$ SD) (Figure 1). Scores of minor invaders were not correlated ($r^2 = 0.005$, $P > 0.05$) with the number of counties in which they were recorded.

Twenty-seven percent (42 species) of the tested species had scores (1 to 6) that indicated the need for further evaluation (20 noninvaders, 16 minor invaders, and 6 major invaders). After the secondary screen was applied, that percentage dropped to 10% (16 species), which is not significantly different than the hypothesized 15% threshold for this category ($X^2 = 3.14$, $P = 0.08$). Of the 16 species left with the evaluate further outcome, nine were a priori categorized as noninvaders, three as minor invaders, and four as major invaders. Of the 26 species whose outcomes were reassigned after the secondary screen, all 11 noninvaders were accepted, 12 of the 13 minor invaders were accepted and 1 was rejected, and 1 of the 2 major invaders was rejected, whereas the other was accepted. Because of the significant reduction in the number of species in this unresolved category and because use of the secondary screen did not obviously bias the outcomes, all

Table 4. Percentage (and absolute number) within each a priori category of invasiveness, or combination of categories, of species with accept, evaluate further, or reject outcomes for the Florida test of the Australian Weed Risk Assessment using the secondary screen developed by Daehler et al. (2004).

Outcome	Noninvader	Minor invader	Major invader	Overall	Combined minor invader and noninvaders	Combined minor and major invaders
Accept	73% (35)	36% (17)	2% (1)		54% (52)	16% (18)
Evaluate further	19% (9)	6% (3)	6% (4)	10% (16)	13% (12)	7% (7)
Reject	8% (4)	58% (28)	92% (57)		33% (32)	77% (85)
Total number	48	48	62	158	96	110

results presented hereafter will be with application of the secondary screen.

Accuracy of the WRA Results in Florida. When species that are major invaders of natural and agricultural systems were examined separately, the overall results were similar for the two groups. Twenty-five invaders in natural areas were rejected (86%), three required further evaluation (10%), and one was accepted (3%). Of the 26 invaders in agricultural systems, 25 (96%) were rejected and 1 (4%) required further evaluation. All of the seven species documented to be invasive in both systems were rejected. We found no differences ($t = 1.63$, df $= 53$, $P = 0.11$) in mean score of the 55 species unique to each system (agricultural invader mean $= 15.3 \pm 6.1$ SD; natural area invader mean $= 12.7 \pm 6.0$ SD). Because of the consistency in results across these systems, only pooled results are presented in the remainder of this analysis.

The Florida results met all three hypothesized accuracy thresholds: at least 90% of the major invaders were rejected by the WRA (92%, 57/62 ; $X^2 = 0.18$, $P = 0.67$), at least 75% of noninvaders were accepted by the WRA (73%, 35/48; $X^2 = 0.111$, $P = 0.74$), and fewer than 15% of species required further evaluation (10%, 16/158; $X^2 = 3.14$, $P = 0.08$) (Table 4).

When the minor invaders are included within the invader category, the WRA correctly predicted that invasive species should be rejected 77% of the time and correctly accepted 73% of all noninvader species tested (columns in Table 5). Thus, the overall percentage of correct predictions with the secondary screen was 76% (rejected invaders + accepted noninvaders = 120/158 predictions). When minor invaders are included in the noninvader category, the WRA correctly predicted that invasive species should be rejected 92% of the time and noninvasive species would be correctly accepted 54% of the time (columns in Table 6). Thus, the overall percentage of correct predictions with the secondary screen was 69% (109/158), though not significantly different than the alternative combination ($X^2 = 3.58$, $P = 0.06$). In both cases, 10% of the overall predictions are species representing further evaluation, counted here as "incorrect" responses.

ROC Analysis. The areas under both ROC curves were significantly different than 0.5 ($P < 0.001$), indicating the strong ability of the WRA to discriminate between invaders and noninvaders for our dataset, regardless of whether minor invaders were categorized as noninvaders or invaders (Figure 2). When Florida's minor invaders were grouped with major invaders, the area under the ROC curve was 0.91 ± 0.023 SE (Figure 2A), not significantly different ($z = 0.65$, $P = 0.52$) than the 0.89 ± 0.025 SE area found when minor invaders were grouped with noninvaders (Figure 2B).

ROC curves can also be used to demonstrate the tradeoffs between correct rejections of invaders and

Table 5. Predicted results (number of species) for 48 a priori minor invader and 62 a priori major invader species ("invader" group) compared to 48 a priori noninvader species ("noninvader" group) with application of the secondary screen.

	Actual			
	Noninvader	Invader (major and minor)	Total	Reliability: Likelihood of correct decision
Predicted:				
Accept	35	18	53	66% (35/53)
Evaluate	9	7	16	
Reject	4	85	89	96% (85/89)
Total	48	110	158	
Accuracy:				
Percent correct of all outcomes:	73% (35/48)	77% (85/110)		

Table 6. Predicted results (number of species) for 48 a priori noninvader species and 48 a priori minor invader species (''noninvader'' group) compared to 62 a priori major invader species (''invader'' group) with application of the secondary screen.

	Actual			
	Noninvader (noninvader and minor invader)	Invader	Total	Reliability: Likelihood of correct decision
Predicted:				
Accept	52	1	53	98% (52/53)
Evaluate	12	4	16	
Reject	32	57	89	64% (57/89)
Total	96	62	158	
Accuracy:				
Percent correct of all outcomes:	54% (52/96)	92% (57/62)		

incorrect rejections of noninvaders at different score cutoffs between the accept and reject outcomes (no evaluate further outcome can be included in ROC analysis). The lower the cutoff score, the higher both the correct rejection of invaders and the incorrect rejection of noninvaders, though the relationship is not linear (Figure 2). The ROC curve for our dataset, grouping minor and major invaders (Figure 2A), shows that achieving a 90% rate of correctly identifying invaders corresponds to a 30% rate of incorrectly rejecting noninvaders. This combination would occur if species that receive a score of 3 or higher are rejected, and species that receive a score below 3 are accepted. If the cutoff score were raised to 6, only 80% of invaders would be correctly rejected, but fewer than 10% of noninvaders would be incorrectly rejected. Alternatively, increasing the correct rejection rate to 95% would require a cutoff score of 1, but 50% of the noninvaders would be incorrectly rejected (Figure 2A).

Comparison of WRA Results with Simpler Approaches. Caley and Kuhnert (2006) proposed that a four-question decision tree might have equivalent accuracy to the 49 questions of the WRA. The tree addresses whether propagule introduction is intentional or not, whether the species is a weed elsewhere or not, whether the species has naturalized beyond its native range, and whether or not the species has been domesticated. We were able to use the tree for 151 of the 158 species. Although this method appeared accurate for the major invader group, with all 61 species tested predicted to be invasive, it resulted in high predictions of invasiveness in the minor invaders (91% of the 47 species tested) and noninvaders (88% of the 43 species tested).

We also tested the accuracy of prediction when only the question of whether the species is invasive elsewhere is asked. This question had already been addressed for all 158 species in WRA questions 3.02, 3.03, and 3.04. If any of these were answered with a ''yes,'' we scored the species positively with respect to this question, leading to a reject outcome (there were no evaluate further outcomes in this analysis). For the invaders, this resulted in a 92% (57/62) correct rejection rate. For minor invaders, 67% (32/48) were rejected and 33% (16/48) were accepted. For the noninvaders, we found a 92% (44/48) correct acceptance rate, and an 8% (4/48) incorrect rejection rate. These proportions are the same (X^2 = 0.18, P = 0.67 for invaders) or more accurate (X^2 = 4.55, P = 0.03 for noninvaders) than our hypothesized accuracy rates for the full 49-question WRA.

Discussion

Accuracy of the WRA in Florida. The Florida WRA test met all the hypothesized accuracy levels. Using our original a priori categorization of noninvaders, minor invaders, and major invaders, the WRA with the secondary screen developed by Daehler et al. (2004) correctly rejected over 90% of test species that have been documented to be invasive in Florida (92%) and correctly accepted a number of noninvaders not different than 75% (73%). The incorrect rejection of noninvaders was 8% and the remaining 19% required further evaluation. For all species tested, we found only 10% required further evaluation.

Incorporation of the secondary screen for species falling in the evaluate further category (Daehler et al. 2004) reduced the number in that category by 62% (from 42 to 16 species), similar to the 62 and 67% reductions reported by Kato et al. (2006) and Daehler et al. (2004), respectively. Of the 26 species for which the secondary screen provided an outcome of accept or reject, only two (12%) were miscategorized (one invader and one non-invader). Accuracy of classification of minor invaders is less obvious because of the ambiguity of the correct outcome for this group; however, 36% were accepted (including 12 species accepted using the secondary screen) and 58% rejected (one species rejected using the screen).

Without use of the secondary screen, minor invaders were rejected or required further evaluation 90% (16

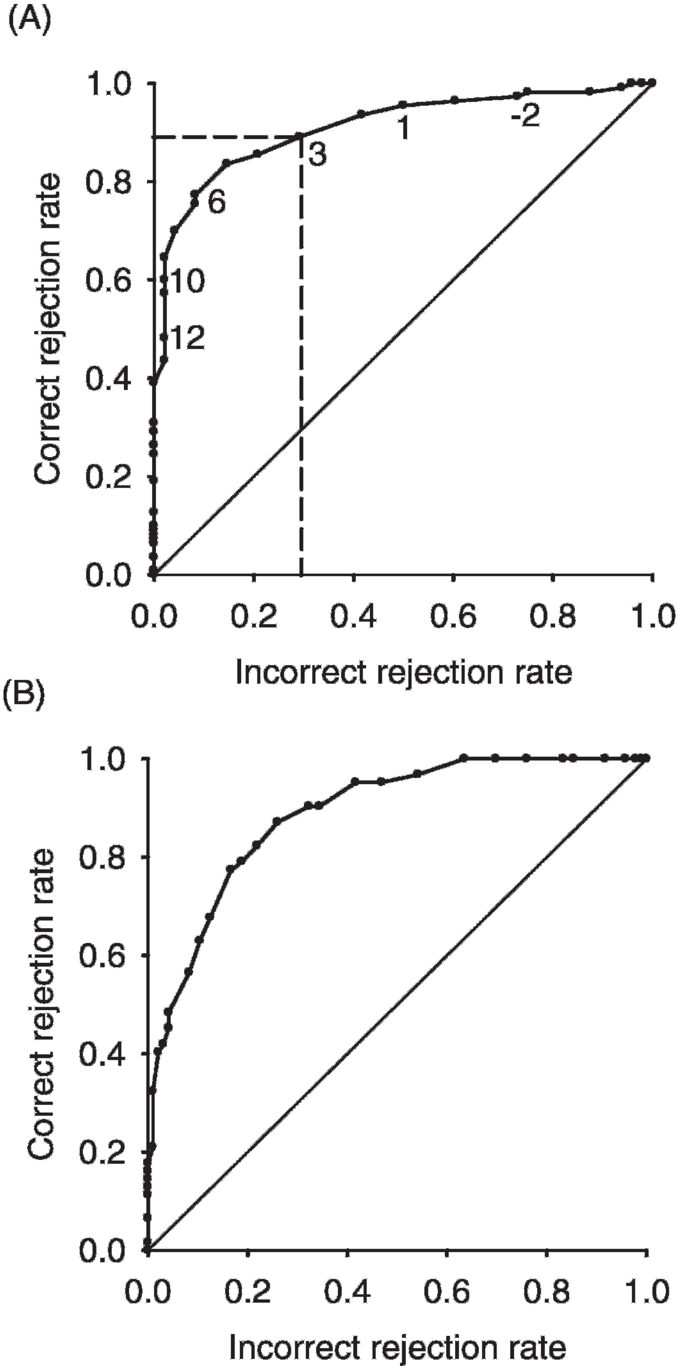

Figure 2. Receiver Operating Characteristic curves for Florida datasets. Diagonal line represents an area of 0.5, which would indicate complete inability to distinguish invaders from noninvaders. (A) Minor invaders and major invaders combined: area under the curve = 0.91 (± 0.023 SE). Numbers along curve are examples of cutoff Weed Risk Assessment scores associated with tradeoffs between correct and incorrect rejection of species (see text). (B) Minor invaders and noninvaders combined: area under the curve = 0.89 (± 0.025 SE).

evaluate further and 27 reject = 43/48) of the time, similar to the 85% found in Australia (Pheloung et al. 1999). After application of the secondary screen, this value was reduced to 64%. The secondary screen may be increasing the accuracy of the WRA by reducing the probability that species with low potential to become major invaders are rejected. Examined differently, because 92% of the species originally requiring further evaluation but reassigned with the secondary screen were not major invaders (11 noninvaders + 13 minor invaders) the secondary screen appears to increase the number of noninvaders that are correctly accepted while keeping the risk of incorrectly accepting major invaders relatively low. Based on these results, we would recommend routine application of the secondary screen whenever the WRA is used.

Overall, if an unknown species were proposed for introduction to Florida, the probability of making a correct rejection or acceptance decision (reliability, sensu Smith et al. 1999) is 96 and 66%, respectively, when minor and major invaders are both considered invaders (calculated across the rows in Table 5). The relationship reverses if minor invaders are considered essentially noninvasive because of negligible impacts: 64% of reject decisions and 98% of accept decisions would be correct (rows in Table 6). Selection of the "best" approach, both in terms of whether to be more precautionary about minor invaders and more accurate on the reject or accept side, will depend on the perception of risk, where the burden of that risk falls, and the regulatory environment involved (Perrins et al. 2002; Stohlgren and Schnase 2006).

We found no evidence that species found in agricultural or natural areas in Florida were assessed differently by the WRA (see also Daehler et al. 2004), validating the use of this tool for protecting both agricultural and natural systems. Because the WRA includes questions (Table 1) that were originally designated to specifically address agricultural weeds (eight questions), environmental weeds (12 questions), and weeds of both or intermediate habitats (25 questions), the result is not surprising. The remaining four questions are not considered to be habitat related. Aquatic plants are the only group of species underrepresented by our test; this group should be evaluated once a suitable set of noninvasive aquatic species has been identified. However, we have no reason to suspect that the Australian approach for aquatics would not be as accurate in Florida as it appears for other life forms.

A significant positive correlation between the WRA scores and the number of counties in which a species was recorded would have suggested that the WRA score could provide a prediction of where a species might fall on the invasiveness continuum. Instead, the absence of any correlation illustrates some important limitations in what we can expect from the WRA, supporting the expectation that the score indicates the likelihood of invasion rather than the impact or spread resulting from invasion (P. Pheloung, personal communication). Local factors that are not addressed by this general WRA, such as availability and connectivity of suitable habitats, actual amount of propagule pressure, competing species, general herbivores and pathogens, founder effects, etc., can significantly influence whether a species capable of survival, reproduction, and spread in an introduced range will become common or detrimental (Mack 1996; Thuiller et al. 2005).

Predictions of the WRA are based on the potential of a species (e.g., optimal reproductive and dispersal capabilities) as well as its known worst behavior elsewhere, so the predictions relate to the potential ''endpoint'' status of a species. Although the 50-yr minimum presence for noninvaders should prevent miscategorization of most recently arrived but not yet widespread or detected invaders, some apparent noninvaders or minor invaders may yet turn into major invaders after a longer lag phase has passed (Hobbs and Humphries 1995; Kowarik 1995). Thus, instead of regarding the rejection of minor invaders and noninvaders as a failure of the WRA, these results may be a warning of the potential of some species to become invasive in the future. This precautionary result may actually increase the long-term accuracy of the predictions made.

Implementation of the WRA. We found that we could apply the WRA to all species tested. The WRA requires that a minimum of 10 out of the 49 questions be answered (distributed among three categories) (Pheloung et al. 1999). The average of 36 questions answered for the 124 species tested here was similar to other tests (Daehler and Carino 2000; Daehler et al. 2004; Křivánek and Pyšek 2006) and indicates that application of this WRA should be possible for most species.

Daehler and Carino (2000) report that it takes 6 h per species, on average, to address the 49 WRA questions. That effort was similar to the over 5 h it took per species in the Bonin Islands (Kato et al. 2006), but substantially shorter than the 16 to 24 h per species was necessary in Australia (Keller et al. 2007) and in our study. If we had used climate-matching programs, the time for comparing home and invaded-range climate variables to those in the potential new range would add time to the assessment procedure, although previously compiled climate data (e.g., Thuiller et al. 2005) would facilitate the process. However, all these levels of effort are significantly lower than the 2 to 8 wk required for current approaches to screening employed in the United States (Parker et al. 2007). Thus, the WRA appears to provide an efficient evaluation of likely invasiveness. However, this method includes less extensive evaluation of the potential for a species to host damaging pests or pathogens than required for the U.S. Department of Agriculture Animal and Plant Health Inspection Service approach (USDA-APHIS 2004). That evaluation would add to the time required for species assessment.

The use of more than two a priori categories reduces the ease of reporting an overall rate of correct WRA outcomes for a given test, because the ''correct'' outcome for minor invaders is unclear. Varying definitions of different positions along the invasion continuum also confuse this effort (see Gordon et al. 2008). The WRA was intended to be precautionary, accurately rejecting major invaders, rarely rejecting noninvaders, and rejecting or requiring further evaluation of most minor invaders (Pheloung et al. 1999). Depending on the degree to which a voluntary program or regulatory entity or government wishes to limit risk relative to potential opportunity costs, species that are defined as naturalized (reproducing outside cultivation but showing no signs of aggressive spread; sensu Richardson et al. 2000), may be considered a potential risk to be avoided or a benign invader that can be tolerated.

Comparison of WRA Results to Abridged Approaches. When we tested whether the four-question decision tree proposed by Caley and Kuhnert (2006) would produce results similar to the 49-question WRA, virtually all species were predicted to be invasive. In the test using Australian species, 94% of invaders and 37% of noninvaders were accurately classified (Caley and Kuhnert 2006). Combining minor and major invaders to best compare to these results, our test shows that this method accurately classified 96% of invaders and 12% of noninvaders. The significantly lower ROC curve area found for this decision tree compared to the original Australian dataset (Caley and Kuhnert 2006) confirms the lower accuracy of this approach.

The elevated prediction of invasiveness using the four-question tree is largely because a positive answer to both whether a species has been dispersed intentionally and whether it has naturalized outside its native range results in classification as invasive (Caley and Kuhnert 2006). We found that 78% of the species we tested have been dispersed intentionally. Of these species, 68% have naturalized outside their native range. Eighty-five percent of those species that have not been dispersed intentionally are considered weeds elsewhere, which also results in a classification as invasive (Caley and Kuhnert 2006). Although we need to evaluate our interpretation of the questions relative to that used in Australia, our current conclusion is that this simpler approach will not result in sufficient accuracy for implementation.

The test of the single question ''Is the species is a weed elsewhere?'' resulted in significantly more accurate predictions than the Caley and Kuhnert (2006) decision tree, even though that question is included in their tree. The significant contribution of this one question has been documented elsewhere (Daehler et al. 2004; Mack 1996;

Reichard and Hamilton 1997; Rejmánek et al. 2005). Roughly 90% of Australia's "noxious weeds" are recorded as weeds elsewhere, for example (Panetta 1993). However, as opportunities for trade and plant exploration in new regions continue to increase, numerous species that have not yet been translocated are likely to be proposed (Rejmánek et al. 2005). Under such circumstances the predictive accuracy of a "no" answer to this single question could be reduced (Daehler et al. 2004). Instead, because the accuracy of this question was the same or higher in our test than that of the full 49-question WRA, this one question would be an effective "first cut" for species proposed for introduction as has been proposed in a simplified WRA system (FAO 2005). Species with a "yes" response would be rejected but all other species would be evaluated using the full WRA.

Implications of Implementing a WRA. Research in Australia has demonstrated the cost-effectiveness of preventing introduction of invasive species (Keller et al. 2007; Smith et al. 1999). A conservative analysis, described as underestimating the costs of damaging invaders and overestimating the benefits of species introduced, suggests that implementation of the WRA in Australia resulted in reduced economic damage in just over 10 yr with up to $1.8 billion in savings over 50 yr (Keller et al. 2007). Given that implementation of this approach in the United States would require modification of existing procedures on the parts of both plant importers and regulators, better understanding of the implications of this approach may be necessary. Further research to determine the assessment outcomes (accept or reject) for species that have been recently imported to a new geography would provide a useful indication of the proportion of future introductions that could be in contention.

The cutoff WRA scores between accept, evaluate further, and reject were chosen by Pheloung et al. (1999) to meet Australia's precautionary goals. However, these cutoffs can be adjusted to fit the needs of policy makers (Hughes and Madden 2003). Raising the cutoff scores for the evaluate further outcome would allow more noninvaders to be correctly accepted, but would also mean that more invaders would be incorrectly accepted. Conversely, lowering the cutoffs would allow more invaders to be correctly rejected, but it would mean that more noninvaders would be incorrectly rejected.

These tradeoffs can also be examined with ROC curve analysis (Figure 2). Although the evaluate further category cannot be included in this approach, the relative probabilities of correct and incorrect rejection can be compared when a specific threshold between the accept and reject decisions are selected. Our dataset suggests that a cutoff between 3 and 5 would allow correct rejection of invaders 80 to 90% of the time, and incorrect rejection of noninvaders 15 to 30% of the time. Corresponding to the shape of the curve beyond about 0.2 on the x-axis, the incorrect rejection rate is much more sensitive to increases in the cutoff point than is the correct rejection rate. This result is consistent with that found for the Australian dataset, which had a curve area of 0.89 $\pm$ 0.018 SE (Caley and Kuhnert 2006), consistent with our areas (Figure 2). This methodology for explicitly quantifying tradeoffs in prediction accuracy should facilitate policy decisions if the WRA is further explored for implementation.

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Appendix A. Species (158) used for the Florida Weed Risk Assessment (WRA) test and resulting outcomes.

	Species	A priori category	WRA score	Outcome[a]
Rosary pea	*Abrus precatorius* L.	Major invader	16	R
Florida Keys Indian mallow	*Abutilon hirtum* (Lam.) Sweet	Minor invader	5	R[b]
Trailing abutilon	*Abutilon megapotamicum* (A. Spreng.) A. St.-Hil. & Naudin	Noninvader	2	E
Cuban copperleaf	*Acalypha setosa* A.Rich.	Minor invader	0	A
American century plant, century plant	*Agave americana* L.	Minor invader	14	R
Thread-leaf agave	*Agave filifera* Salm-Dyck	Noninvader	−1	A
Common corncockle	*Agrostemma githago* L.	Minor invader	9	R
Silver hairgrass	*Aira caryophyllea* L.	Minor invader	9	R
Mimosa, silk tree	*Albizia julibrissin* Durazz.	Major invader	21	R
Indian walnut	*Aleurites moluccana* (L.) Willdenow	Minor invader	3	E
Brownbud allamanda, golden trumpet, yellow allamanda	*Allamanda cathartica* L.	Minor invader	12	R
Bush allamanda	*Allamanda schottii* Pohl	Noninvader	7	R
Shellplant	*Alpinia zerumbet* (Pers.) B. L. Burtt & R. M. Sm.	Minor invader	5	A[b]
Brazilian joyweed	*Alternanthera brasiliana* (L.) Kuntze	Minor invader	13	R
Smooth joyweed	*Alternanthera paronichyoides* A. St.-Hil.	Minor invader	6	A[b]
Palmer amaranth	*Amaranthus palmeri* S. Watson	Major invader	11	R
Spiny amaranth	*Amaranthus spinosus* L.	Major invader	18	R
Perennial peanut	*Arachis glabrata* Benth.	Noninvader	−11	A
Jackfruit	*Artocarpus heterophyllus* Lam.	Noninvader	−1	A
Butterfly tree, purple orchid tree	*Bauhinia purpurea* L.	Minor invader	8	R
Orchid tree	*Bauhinia variegata* L.	Major invader	7	R
Spanishneedles	*Bidens pilosa* L.	Major invader	19	R
Foolproof plant	*Billbergia pyramidalis* (Sims) Lindl.	Minor invader	−1	A
Red dwarf tree fern, red Brailian tree fern	*Blechnum brasiliense* Desv.	Noninvader	0	A
Red silk-cotton tree	*Bombax ceiba* L.[c]	Noninvader	−4	A
Bracted strawflowers	*Bracteantha bracteata* (Vent.) Tzvelev	Noninvader	2	A[b]
Angel's trumpet, thorn apple	*Brugmansia* × *candida* Pers[d]	Noninvader	2	E
Butterfly-bush, pole butterflybush	*Buddleja officinalis* Maxim.	Noninvader	1	A[b]

Appendix A. Continued.

	Species	A priori category	WRA score	Outcome[a]
Powderpuff tree, stickpea	*Calliandra haematocephala* Hassk.	Minor invader	1	A[b]
Citrus-leaved bottle-brush, crimson bottlebrush, lemon bottlebrush, red bottlebrush	*Callistemon citrinus* (Curtis) Skeels	Noninvader	−1	A
China aster	*Callistephus chinensis* (L.) Nees	Noninvader	2	A[b]
Texasweed	*Caperonia palustris* (L.) A. St.-Hil.	Major invader	5	E
Amatungula, num-num	*Carissa bispinosa* (L.) Desf. ex Brenan	Noninvader	0	A
St John's bread	*Ceratonia siliqua* L.	Noninvader	1	A[b]
Floss-silk tree	*Chorisia speciosa* (A. St.-Hil.) Ravenna	Noninvader	−5	A
Carolina coralbead, cocculus, snail seed	*Cocculus laurifolius* DC.	Noninvader	0	A
Asian nakedwood, asiatic colubrina, latherleaf	*Colubrina asiatica* (L.) Brongn.	Major invader	19	R
Benghal dayflower, tropical spiderwort	*Commelina benghalensis* L.	Major invader	17	R
Carrotwood	*Cupaniopsis anacardioides* (A. Rich.) Radlk.	Major invader	3	R[b]
–	*Cyanotis cristata* D. Don	Noninvader	5	E
Wild cucumber	*Cyclanthera pedata* (L.) Schrad.	Noninvader	1	E
Yellow nutsedge	*Cyperus esculentus* L.	Major invader	19	R
Fuzzy flatsedge	*Cyperus pilosus* Vahl[e]	Minor invader	7	R
Florida beggerweed	*Desmodium tortuosum* (Sw.) DC.	Major invader	14	R
Air-potato	*Dioscorea bulbifera* L.	Major invader	19	R
Chinese goddess bamboo	*Drepanostachyum falcatum* (Nees) Keng f.	Noninvader	−3	A
Cardamon	*Elettaria cardamomum* (L.) Maton	Noninvader	−1	A
Pothos	*Epipremnum pinnatum* cv. Aureum (L.) Engl.	Major invader	11	R
Fortyflower lovegrass	*Eragrostis cumingii* Steud.	Minor invader	2	A[b]
Surinam cherry	*Eugenia uniflora* L.	Major invader	12	R
Christmas star, poinsettia	*Euphorbia pulcherrima* Willd. ex Klotzsch[f]	Noninvader	−3	A
Fountain bamboo	*Fargesia nitida* (Mitford) Keng f. ex T. P. Yi	Noninvader	−4	A
Feijoa, pineapple guava	*Feijoa sellowiana* (O. Berg) Burret[g]	Noninvader	5	E
Laurel fig	*Ficus microcarpa* L. f.	Major invader	12	R
Climbing fig	*Ficus pumila* L.	Minor invader	10	R
Mosaic plant, nerve plant, silver-net plant	*Fittonia verschaffeltii* (Lindl. ex hort. Veitch) Brummitt	Noninvader	−3	A
Round kumquat	*Fortunella japonica* (Thunb.) Swingle	Noninvader	−3	A
Jagua	*Genipa americana* L.	Noninvader	3	A[b]
Flamelily	*Gloriosa superba* L.	Minor invader	14	R
Common globe amaranth	*Gomphrena globosa* L.	Noninvader	8	R
Velvetplant	*Gynura aurantiaca* (Blume) DC.	Minor invader	−4	A
Algerian ivy	*Hedera canariensis* (Willd.) Cout.	Noninvader	13	R
Silverleaf sunflower	*Helianthus argophyllus* Torr. & A. Gray	Minor invader	3	A[b]
Mahoe, sea hibiscus	*Hibiscus tiliaceus* (L.) Fryxell[h]	Major invader	11	R
Comb bushmint	*Hyptis pectinata* (L.) Poit.	Minor invader	11	R
Cogongrass	*Imperata cylindrica* (L.) P. Beauv.	Major invader	26	R
Hairy indigo	*Indigofera hirsuta* L.	Major invader	13	R

Appendix A. Continued.

	Species	A priori category	WRA score	Outcome[a]
Lady Doorly's morning-glory	*Ipomoea horsfalliae* Hook.	Noninvader	4	A[b]
Palm beachbells	*Kalanchoe gastonis-bonnieri* Raym.-Hamet & H. Perrier	Minor invader	2	A[b]
Christmastree plant, Christmas tree kalanchoe	*Kalanchoe laciniata* (L.) DC.	Minor invader	2	A[b]
Life plant, cathedral bells	*Kalanchoe pinnata* (Lam.) Pers.	Major invader	16	R
Henbit	*Lamium amplexicaule* L.	Major invader	18	R
Lion's-ear	*Leonotis nepetifolia* (L.) R. Br.	Minor invader	14	R
Big blue lilyturf, border grass, lilyturf	*Liriope muscari* (Decne.) L. H. Bailey	Noninvader	7	R
Lychee	*Litchi chinensis* Sonn.	Noninvader	−7	A
Japanese honeysuckle	*Lonicera japonica* Thunb.	Major invader	19	R
'Gold Flame' honeysuckle	*Lonicera* L. × *heckrottii* Rehd. [× *americana* × *sempervirens*]	Noninvader	−1	A
Japanese climbing fern	*Lygodium japonicum* (Thunb.) Sw.	Major invader	25	R
Old World climbing fern	*Lygodium microphyllum* (Cav.) R. Br.	Major invader	15	R
Threelobe false mallow	*Malvastrum coromandelianum* (L.) Garcke	Minor invader	8	R
Mazapan, Turks-cap mallow	*Malvaviscus penduliflorus* DC.	Minor invader	−5	A
Sapodilla	*Manilkara zapota* (L.) P. Royen	Major invader	5	E
California burclover	*Medicago polymorpha* L.	Minor invader	11	R
Melaleuca, paper bark	*Melaleuca quinquenervia* (Cav.) S. T. Blake	Major invader	20	R
Redweed	*Melochia corchorifolia* L.	Major invader	10	R
Rock rosemary	*Merremia quinquefolia* (L.) Hallier f.	Minor invader	8	R
Catclaw mimosa	*Mimosa pigra* L.	Major invader	27	R
Sensitive plant	*Mimosa pudica* L.	Minor invader	17	R
Chinese silvergrass	*Miscanthus sinensis* Andersson	Minor invader	14	R
Carpetweed	*Mollugo verticillata* L.	Major invader	8	R
Balsam apple	*Momordica charantia* L.	Major invader	14	R
Orange-jessamine	*Murraya paniculata* (L.) Jack	Minor invader	7	R
Eurasian watermilfoil	*Myriophyllum spicatum* L.	Major invader	25	R
Common myrtle, myrtle	*Myrtus communis* L.	Noninvader	4	E
Heavenly bamboo, nandina	*Nandina domestica* Thunb.	Major invader	12	R
Sword fern	*Nephrolepis cordifolia* (L.) C. Presl	Major invader	11	R
Burma reed, canegrass	*Neyraudia reynaudiana* (Kunth) Keng ex Hitchc.	Major invader	11	R
Sewer vine, onion vine	*Paederia cruddasiana* Prain	Major invader	2	E
Skunk vine	*Paederia foetida* L.	Major invader	19	R
Jerusalem thorn, Mexican palo verde, retama	*Parkinsonia aculeata* L.	Minor invader	18	R
Vaseygrass	*Paspalum urvillei* Steud.	Major invader	13	R
Twin-flowered passion vine	*Passiflora biflora* Lam.	Minor invader	5	A[b]
Bat wing passion flower	*Passiflora coriacea* Juss.	Noninvader	2	E
Crimson fountaingrass	*Pennisetum setaceum* (Forssk.) Chiov.	Minor invader	20	R
Heartleaf philodendron, vilevine	*Philodendron scandens* (Jacq.) Schott	Noninvader	0	A
Senegal date palm	*Phoenix reclinata* Jacq.	Major invader	5	E
Pygmy date palm	*Phoenix roebelenii* O'Brien	Noninvader	5	E
Chamberbitter	*Phyllanthus urinaria* L.	Major invader	13	R
Creeping Charlie	*Pilea nummulariifolia* (Sw.) Wedd.	Minor invader	11	R
Chinese pistache	*Pistacia chinensis* Bunge	Noninvader	1	E

Appendix A. Continued.

	Species	A priori category	WRA score	Outcome[a]
–	*Pitcairnia karwinskyana* Schult. & Schult. f.	Noninvader	−3	A
Silverback fern	*Pityrogramma calomelanos* (L.) Link	Minor invader	12	R
Annual bluegrass	*Poa annua* L.	Major invader	26	R
Common purslane	*Portulaca oleracea* L.	Major invader	23	R
Mammee sapote	*Pouteria sapota* (Jacq.) H. E. Moore & Stearn	Noninvader	−3	A
Spider brake	*Pteris multifida* Poir.	Minor invader	9	R
Spinyfruit buttercup	*Ranunculus muricatus* L.	Minor invader	7	R
Smallflower buttercup	*Ranunculus parviflorus* L.	Minor invader	4	A[b]
Formosa azalea	*Rhododendron simsii* Planch.	Noninvader	0	A
Brazilian pusley	*Richardia brasiliensis* Gomes	Major invader	7	R
Florida pusley	*Richardia scabra* L.	Major invader	8	R
Itchgrass	*Rottboellia cochinchinensis* (Lour.) Clayton	Major invader	22	R
Monkey plant	*Ruellia makoyana* hort. Makoy ex Closon	Noninvader	−1	A
Mexican petunia	*Ruellia tweediana* Griseb.[i]	Major invader	11	R
Curlydock	*Rumex crispus* L.	Major invader	26	R
Fiddle dock	*Rumex pulcher* L.	Minor invader	11	R
Leatherleaf fern, seven weeks fern	*Rumohra adiantiformis* (G. Forst.) Ching	Minor invader	3	A[b]
Sugarcane	*Saccharum officinarum* L.	Minor invader	4	A[b]
Scarlet sage	*Salvia splendens* Sellow ex Schult.	Noninvader	4	A[b]
Bowstring hemp	*Sansevieria hyacinthoides* (L.) Druce	Major invader	14	R
Chinese tallowtree, popcorn tree	*Sapium sebiferum* (L.) Small	Major invader	18	R
Beach naupaka, half-flower, scaevola	*Scaevola sericea* (Gaertn.) Roxb.	Major invader	14	R
Schefflera, Queensland umbrella tree	*Schefflera actinophylla* (Endl.) Harms[j]	Major invader	14	R
Brazilian pepper	*Schinus terebinthifolius* Raddi	Major invader	19	R
German knotgrass	*Scleranthus annuus* L.	Minor invader	5	E
Snow rose	*Serissa foetida* (Thunb.) Thunb.	Noninvader	−4	A
West Indian bristlegrass	*Setaria setosa* (Sw.) P. Beauv.	Minor invader	1	A[b]
Blue fieldmadder	*Sherardia arvensis* L.	Minor invader	7	R
Prickly sida	*Sida spinosa* L.	Major invader	9	R
Wideleaf bamboo	*Sinocalamus latiflorus* (Munro) McClure	Noninvader	−2	A
Tropical soda apple	*Solanum viarum* Dunal	Major invader	24	R
Corn spurry	*Spergula arvensis* L.	Major invader	20	R
Smutgrass	*Sporobolus indicus* (L.) R. Br.	Major invader	18	R
Common chickweed	*Stellaria media* (L.) Vill.	Major invader	25	R
Cowpea witchweed	*Striga gesnerioides* (Willd.) Vatke	Major invader	15	R
African milk bush	*Synadenium grantii* Hook. f.	Noninvader	3	A[b]
Jambolan, Java plum	*Syzygium cumini* (L.) Skeels	Major invader	9	R
Incised halberd fern	*Tectaria incisa* Cav.	Major invader	2	A[b]
Rice paper plant	*Tetrapanax papyriferus* (Hook.) K.Koch	Minor invader	6	E
Seaside mahoe	*Thespesia populnea* (L.) Sol. ex Corrêa	Major invader	13	R
Confederate jasmine, star jasmine	*Trachelospermum jasminoides* (Lindl.) Lem.	Minor invader	−2	A
White-flowered wandering jew	*Tradescantia fluminensis* Vell.	Major invader	18	R
Didier's tulip	*Tulipa gesneriana* L.	Noninvader	3	A[b]

Appendix A. Continued.

	Species	A priori category	WRA score	Outcome[a]
Tropical signalgrass	*Urochloa subquadripara* (Trin.) R. D. Webster[k]	Major invader	8	R
Voa vanga, Spanish tamarind	*Vangueria madagascariensis* J. F. Gmel.	Noninvader	3	A[b]
Rattail fescue	*Vulpia myuros* (L.) C. C. Gmel.	Minor invader	16	R
Desert palm, Mexican Washington palm, Washington fan palm, Washington palm	*Washingtonia robusta* H. Wendl.	minor invader	10	R
Silky wisteria	*Wisteria brachybotrys* Siebold & Zucc.	noninvader	2	A[b]

[a] Reject (R) results predict that the species will be invasive, Accept (A) results predict that the species will not be invasive, and Evaluate Further (E) results are not definitive.

[b] Result obtained after using the secondary screen.

[c] = *Bombax malabaricum.*

[d] = *Brugmansia arborea, Datura arborea, Datura candida.*

[e] = *Cyperus paniculatus.*

[f] = *Poinsettia pulcherrima.*

[g] = *Acca sellowiana.*

[h] = *Talipariti tiliaceum.*

[i] = *Ruellia brittoniana.*

[j] = *Brassaia actinophylla.*

[k] = *Urochloa distachya.*