Developing an Aquatic Weed Risk Assessment tool for Florida and the U.S.

Final report on cooperative agreement:

W912HZ-10-2-0014

United States Army Corps of Engineers

Submitted by:
Doria R. Gordon
Crysta A. Gantz
University of Florida
The Nature Conservancy

March 2011

Missouri Botanical Garden photo

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Introduction

Global movement of non-native species has accompanied human movement for thousands of years (Ryerson 1967, Winters 1967). Aquatic species like water lettuce (*Pistia stratiotes*) entered Florida with the Spanish settlers in the late 1500s (Schmitz et al. 1993). However, both the frequency of introductions and the number of species involved have increased exponentially in recent years (Kay and Hoyle 2001, Maki and Galatowitsch 2004). For example, between 1998 and 2003 the number of households in the U.S. with water gardens quadrupled (Crosson 2005) and globally the trade in species for aquaria and water gardens is growing by 14% per year (Padilla and Williams 2004). Aquatic plant species, regardless of regulated status, are internationally available from on-line commercial and hobbyist sources (Kay and Hoyle 2001).

While clearly not all aquatic plant species are invasive when introduced into new habitats, freshwater aquatic and semi-aquatic plants have a higher probability of becoming invasive than species from terrestrial plant families (Daehler 1998). Nineteen invasive aquatic plant species in 15 families are listed among the IUCN's 100 of the worst plant and animal global invaders (Lowe et al. 2000). This high probability of invasiveness, coupled with the increased interest in aquaria, water gardening, and other horticultural efforts, has resulted in a substantial proportion of aquatic invaders derived from intentional import. For example, 75% of the aquatic invasive plants in New Zealand were imported for horticultural use (Champion and Clayton 2000) and 76% of all aquatic plants introduced into southern New England are horticultural escapes (Les and Mehrhoff 1999).

By 2004 the global trade in aquaria and water garden species was generating $25 billion annually (Padilla and Williams 2004), of which in 2003, at least $1.56 billion represented U.S. revenues (Crosson 2005). However, the consequences of aquatic plant invaders are economically and ecologically expensive. Invasive aquatic plant species are responsible for an estimated $110 million in control costs and damage to navigation, recreation, and agriculture in the U.S. annually (Pimentel et al. 2005). Florida alone spends $20 million annually to control *Hyrilla verticillata* (Koschnick 2007). Additionally, invasive aquatic plants have substantial negative impacts on natural systems and the abundance of native plant and animal species. These include direct competitive impacts and indirect alterations to physical factors such as water chemistry, hydrologic regime, temperature, sedimentation rates, and habitat composition and connectivity (Schmitz et al. 1993, Van et al. 1999, Champion and Clayton 2000). Populations of native animal species can also be negatively impacted (Arthington et al. 1983, Schmitz et al. 1993, Ciruna et al. 2004).

The substantial impacts of these species, the majority of which are intentionally introduced to new habitats, indicate the need for an effective screening system to reduce the probability of importing new invaders. Ideally, this system would also provide data for prioritizing management of existing species. Earlier work testing the Australian Weed Risk Assessment (AWRA; Pheloung et al. 1999) demonstrated that this system accurately identifies major invaders 95% of the time regardless of the scale or geography and climate involved (Gordon et al. 2008). The AWRA consistently identifies non-invaders 70% of the time on average, with roughly 10% predicted to become invasive, and the remainder requiring further evaluation (Gordon et al. 2008). Implementation of a screening system with this accuracy has been demonstrated to have become cost effective for Australia within a decade, and was projected to save that country US $1.67 billion over 50 years (Keller et al. 2007). The plant risk assessment methodology currently employed by the USDA-APHIS-PPQ-CPHST-PERAL (Plant Epidemiology and Risk Analysis Laboratory) for evaluation of species as potentially noxious weeds is partially based on the AWRA and has similar accuracy (A. Koop 2010, pers. comm.).

However, efforts to test this tool have primarily focused on terrestrial plant species (Gordon and Gantz 2011). Aquatic plant species (emergent, floating, or submerged) are penalized with an additional five points (none of the other 48 questions in this additive system incurs more than 2 points; most result in addition or subtraction of one point), but are otherwise subject to the same questions as terrestrial species in the AWRA (Pheloung et al. 1999). Since scores over 6 result in the prediction that a species has a high probability of becoming invasive, and since no questions about aquatic environments or impacts to those environments are included in the AWRA, aquatic plants are more likely to be predicted to be invaders than other life forms. We have demonstrated that the AWRA correctly identifies all of the major invaders as invasive, but incorrectly identifies 83% of the non-invaders also as invasive in a U.S. test involving 149 species (Gordon and Gantz 2011).

In New Zealand, concern that the AWRA was too restrictive for use on aquatic species resulted in development of a predictive tool specifically for this group (Champion and Clayton 2000, 2001) that is used for both regulatory and management purposes (Champion et al. 2008). However, the accuracy of the New Zealand aquatic plant risk assessment has not previously been tested at national or sub-national scales. This project addresses these knowledge gaps by addressing four research objectives:

1. Use existing data on known aquatic plant invaders and non-invaders to develop a screening tool that differentiates between these groups with a goal of over 80% accuracy.

2. Evaluate whether modification of the tool is necessary to maintain accuracy levels in temperate versus sub-tropical regions, or whether a single tool might be used for the full U.S.

3. Evaluate thresholds for distinguishing between minor and major invaders in addition to that for distinguishing between invaders and non-invaders.

4. Validate the proposed screening tool using available diagnostic approaches on a separate suite of species.

Preparation of this report, with results and recommendations for the applicability of a tool modified from the New Zealand approach for Florida, the Great Lakes and the U.S. and any necessary additional needs for development of an effective screening tool, was objective 5.

Methods

Aquatic plant risk assessment model

The model we used (Table 1) for the U.S. (henceforth "AqWRA"), is modified from the aquatic plant risk assessment currently in regulatory use in New Zealand (Champion and Clayton 2000, 2001a, b). We started with the New Zealand assessment, making basic modifications to the temperature tolerance question and the question about invasiveness elsewhere for relevance to both the full U.S. and to the specific regions of Florida and the Great Lakes. The regions were selected because they have different environmental conditions and substantial costs associated with aquatic plant invaders. We did not alter the scoring for these questions. Additionally, we included three questions (tolerance of flooding/drought; establishment in disturbed areas; establishment in intact vegetation) that had been added to the New Zealand model when it was implemented in eastern Australia (Champion et al. 2008) and Micronesia (P. Champion 2010, pers. comm.). A comparison of the original New Zealand assessment with the AqWRA tested for the U.S. is in Appendix A.

The modified AqWRA temperature tolerance question (1.1) allows the use of a climate model to determine potential tolerance based upon temperature data from the native/naturalized range of the species. When we found no explicit information in the literature about a species' tolerance to cold or hot temperatures, average 3-month low winter and high summer temperatures in the native and naturalized range from the on-line Climate Wizard model (http://www.climatewizardcustom.org/ Global_Historical) was compared to that in the tested region (http://www.climatewizardcustom.org/ US_Historical/). Air temperatures were used as an approximation for water temperatures because the latter data were not available. A score of "0" was assigned to those species that were unlikely to survive freezing or extreme heat and a score of "1" was assigned to those species that were considered likely to survive.

Because of the range of climates in the U.S., the original question in the New Zealand assessment about weediness in other countries based upon climate was altered to reflect the invasiveness of a species in other countries regardless of temperature tolerance (Appendix A). The modified AqWRA question and scoring reads: "5 [points] if species has been reported to be a widespread problem (i.e., a harmful weed in many other countries), 4 if species has been reported to be a harmful weed in 5 or fewer countries, 3 if species has been reported to be naturalized broadly (widespread adventives) in many other countries, 1 if species has been reported to be naturalized in 5 or fewer countries, 0 if not naturalized elsewhere" (Table 1).

We removed a question from the original Champion and Clayton (2000) tool that addresses the extent of suitable habitat still available in the region. This question assumes the species is already present, and is therefore not appropriate for a predictive tool. Additionally, the question assumes accurate habitat type cover data across the region, which is also inconsistently available. If this assessment is to be used as a management prioritization tool, these data could be useful as a supplement for key species of interest.

We also replaced the need for experimental results in the questions on competitive superiority (3.1, 3.2). In New Zealand the original questions are addressed through pair-wise competition experiments (Champion et al. 2007, Champion et al. 2008, Hofstra et al. 2010). These data are generally unavailable in the U.S. and are unlikely to be generated for use in this assessment. As a result, the AqWRA replaces the need for experimental results with questions that ask whether a species can become the dominant vegetation type both within and among growth forms (3.1, 9.1; Table 1).

As in the original model, the scoring in the AqWRA is entirely additive. We anticipate the tool will be used primarily for determining whether proposed species should be permitted for import, sale, or use, or prioritized for management within the region of interest.

Species selection

Aquatic plant species were defined as *attached-floating, erect emergent, free-floating, sprawling emergent*, or *submerged freshwater macrophytes* (Cook et al. 1974). Wetland and riparian species were not included in this analysis because their probability of invasiveness is accurately determined with the AWRA (Gordon et al. 2008) We identified species for assessment from aquatic plant lists, local floras, and information provided by aquatic weed scientists and horticulturalists specializing in aquarium and water garden plants (see Gordon and Gantz 2011). The numbers of naturalized and non-naturalized temperate and tropical non-native species were relatively equivalent.

We used the AqWRA in three geographic regions: sub-tropical Florida, the temperate Great Lakes Basin, and the large and climatically heterogeneous U.S., to test whether its accuracy is dependent upon regional environmental conditions. As a result, the species were divided into three *a priori* categories of non-invasive, minor invader, and major invader based upon status in each of the three regions (Table 2). Major invaders are non-native species that have naturalized in the region of interest and have caused documented ecological impacts (e.g., forming dense mats, altering water chemistry, obstructing water flows); minor invaders are naturalized in the region without documented ecological impacts; non-invaders have not naturalized in the region. Here, naturalized refers to species which are forming self-sustaining, reproductive populations outside of their native range (Richardson et al. 2000). Information about ecological impacts was obtained from scientific journals and floras, as well as on federal, state, county and other regional websites. While it is possible that some of the species categorized as minor invaders may in fact be major invaders, we used the best information in literature and web-based searches to make the determination.

All species included in the analysis have been in the U.S. (either in the trade or naturalized) for at least 30 years (Table 2). This timeframe has been used in other assessments on aquatic plant species (Champion et al. 2008), which may naturalize relatively rapidly compared to terrestrial species (Gordon and Gantz 2011). We identified introduction dates to the U.S. and other countries using vouchered specimens available on-line and other references, including encyclopedias of horticulture and water gardening (e.g., Tricker 1897; Bisset 1905; Stodola 1967). While species may have been introduced earlier, we ceased searching for this information if a date earlier than 1980 was found.

We started with a total of 130 species divided into 60 non-invaders, 31 minor invaders, and 39 major invaders for the full U.S. test (Tables 2, 3). The numbers of species in each *a priori* category varied for the three regional tests (Table 3) for two reasons. First, some species (e.g., *Acorus calamus*) were in different *a priori* categories in the different regions. Second, a few species required further evaluation (e.g., *Ammannia senegalensis*) because we had insufficient data to answer five or more questions for some regions (see below).

Twenty additional species (10 major invaders and 10 non-invaders) were selected to test the AqWRA accuracy (Table 4) at the U.S. level. The species selection process was the same as that for the original species selected for the development of the model, except that the earliest date for the U.S. we found for seven of the ten invaders was after 1980. As species in the invader category are already spreading into new habitats, the date of introduction clearly has not limited their expression of invasiveness. For the validation assessment we used data on species from within the tested region (U.S.) where it was available (e.g., *Glossostigma cleistanthum, Glyceria declinata*). Species for which this was the case are marked in Tables 7 and 8.

Data requirements and confidence

More information is generally available for species that have large naturalized ranges or ecological impacts outside of the U.S. than for species not naturalized outside of their native ranges. Thus, if this tool were used for screening species prior to their introduction to a new region, peer-reviewed data may not be available for all questions. Instead of disregarding a species assessment because of the lack information, we believe it necessary to gather the data available, even if such information is obtained from internet-based sources or “grey literature” from the trades.

However, because we may be more confident about some data sources than others, we incorporated a mechanism to track the type of source data for each question in this tool. Primary literature (P) was classified as peer-reviewed journal articles, floras, monographs, and/or peer-reviewed scientific books. Secondary literature (S) referred to books or websites that referenced primary literature, such as Encyclopedias or Dictionaries of Gardening, or websites that were associated with a university or professional organization with reliable information (e.g., citation of herbarium specimens that could not be accessed, foreign books not available from interlibrary loan). A "G" was assigned to "grey literature," which included mostly information from trade-related websites or blogs/forums.

We developed "default" scoring rules, scores to be assigned under defined conditions if data are not available, for several of the questions (Table A). When these were used, answers were assigned a "D". We created on low ("L") confidence category for question 1.1 (temperature tolerance), which we assigned for use of the Climate Wizard model. The "L" was not in reference to the model itself, only the use of the model data to conclude whether the species would survive in the region. Finally, an "I" was assigned to questions in which the scoring was dependent upon an inference from the data. This approach was used very infrequently, as almost all of the questions could be scored based upon a direct linkage to some form of data. We have not yet determined the best approach for integrating confidence level into interpretation of the results. It is clear, however, that assessments requiring a lot of data of low confidence will be less reliable than assessments that use only data from primary sources. Additional research will be required to determine the influence of data type on the AqWRA accuracy, and we will not discuss these levels further in this report.

Because this tool is intended for predictive use, questions should be answered with data from outside of the region of interest unless the data are not geographically specific. For example, for the U.S. assessment, the only data that could come from within the U.S. included: 1) data from experiments in controlled facilities (e.g., greenhouse experiments); and 2) data that were not dependent upon provenance, such as certain morphological traits (e.g., formation of floating leaves, rhizomes), unless the evidence implied that provenance was a factor in the development of the trait. Other data would be available only from regions outside the one of interest. For example, information from Florida for the assessment of *Nymphoides cristata* was not used for the Florida and U.S. assessments, but was used for the Great Lakes assessment. The availability of these data for regional assessments explains differences in scores and outcomes among the regions for the same species.

However, if the intended use of the tool is to inform management decisions for species already present, data from within the region of interest should be included. For example, the only location in which *Luziola subintegra* is known to naturalize aggressively is Florida (Kunzer and Bodle 2008). If assessed for the U.S. for predictive purposes we would not use that information and would conclude that it has a low probability of being invasive (see below). However, incorporating the data from Florida results in the prediction that *L. subintegra* has a high probability of becoming invasive, suggesting that management now would be prudent. Examples like this one were used to develop recommendations for how scores might be used for management prioritization of species already present in the region.

Defaults

The default scoring rules are listed with each question in the table of questions (Table 1). Many of the default scores are based on the assumption either that: 1) some types of data are generally reported if there is a reasonable amount of information about the species and the impact exists (e.g., toxicity), so a default negative conclusion is appropriate when the impact is not reported; and 2) some questions require information that will never be available for some species (e.g., Species that have never naturalized outside of their native range are unlikely to have been subject to any type of management program, making the "resistance to management" questions (11.1-11.6) irrelevant, resulting in a default score of "0".).

Identification of species requiring further evaluation

The AWRA has empirically determined score thresholds for three potential outcomes for species assessed: *accept* species that have a low probability of becoming invasive, *reject* species with a high probability of becoming invasive, and require *further evaluation* of species with scores falling between the accept and reject outcomes (Pheloung et al. 1999). No thresholds were defined for the New Zealand assessment of aquatic plants (Champion and Clayton 2000). Rather than set a range of scores resulting in the decision that species required further evaluation, we looked for a pattern in the numbers of questions answered to identify a breakpoint for this threshold. Finding no clear pattern, we somewhat arbitrarily set a maximum number of five unanswered questions to identify species in this category.

Because some of the questions are highly related, we did not use the absolute numbers of questions not answered to determine whether further evaluation was necessary. Within each of the two suites of questions addressing either "habitat breadth" (2.1-2.3) and "resistance to management" (11.1-11.6), one unanswered question was counted regardless of the number of total unanswered questions present. For species with no known invasion history, floras are the main source of information about the type of habitat in which a species occurs. Habitat information is based upon where a species has been found, but does not necessarily reflect the full habitat tolerance of the species. Since a "0" score is only assigned when there is evidence that a species does not occur in a particular habitat type, the unanswered questions do not correspond well with the actual range of habitats a species might colonize. Similarly, for species that have naturalized beyond the U.S. we often have little management information. As a result, questions 11.3-11.6 are often all unanswerable and were not independently counted.

Regional/national differences

Three main differences exist among the regional and U.S. assessments. First, while all of the species not naturalized in the U.S. are considered non-invaders, some of the species naturalized in one region but not another were given different *a priori* invasiveness categories for different regions.

The temperatures to which species are exposed vary among the regions (Question 1.1). Freeze tolerance is a consideration for the Great Lakes region, while heat tolerance is a consideration for

Florida (although no data were found for any species that preclude it from survival based upon heat intolerance). Both cold and heat tolerance were considered for the U.S. assessment. A regional screen was initiated to determine which species to include in the regional (Florida and Great Lakes) assessments. Species with a native and/or naturalized range that included Hardiness Zone (NAPPFAST 2007) 7 or below were included in the Great Lakes assessment and Zones 8 or above were included in the Florida assessment. Thus, more species were included in the Florida assessment due to a higher amount of climate tolerance.

The third difference involves the provenance of ecological impacts and has been discussed above (see Data requirements and confidence). Where the tool is intended for predictive purposes, data used will be from beyond the region of interest because the species is unprecedented in that region. Where the tool is used for management purposes, all data relevant to a species should be included.

Data analysis

Using the total score from the AqWRA, we systematically evaluated the accuracy (percent of species correctly classified) resulting from of all possible threshold values (1 to 88) that could be used to distinguish non-invaders from major invaders. Minor invaders were not included in this threshold analysis since their scores were expected to span those of the other two groups. Thus, the analysis allows calculation of the threshold that maximizes accuracy in differentiating non-invaders from major invaders. The Receiver Operating Characteristic (ROC) curve was generated from the classification matrix from each threshold score. An advantage of using the ROC analysis is that it does not require that the prevalence the factors compared (i.e., non-invaders and invaders) be equivalent (Smith et al. 1999). Since we know that the majority of introduced species are not invasive, insensitivity of the analysis to the probability that a species proposed for introduction will become invasive is critical (Smith et al. 1999).

From the ROC curve we calculated the Area Under the Curve (AUC) (Fawcett 2006). The ROC curve is a diagnostic of the sensitivity, the correct classification of invasive species, and specificity, the correct classification of non-invasive species. Integrating under the curve provides the AUC measure. If the AUC is 1.0, the tool perfectly discriminates between invaders and non-invaders, while values near 0.5 would indicate no discrimination capability (Hosmer and Lemeshow 2000). Because we cannot predict whether minor invaders will become more invasive over time, we compared the AUC when minor invaders were classified as non-invaders with when they were classified as major invaders.

We conducted the accuracy, threshold, and AUC evaluations on the AqWRA with subsets of the questions individually or collectively omitted to test the hypothesis that some questions do not aid in discriminating between non-invaders and major invaders. This hypothesis would be supported if we see little change in the accuracy and AUC values when the full set of questions is included, and when some are removed, allowing simplification of the tool. The questions involved included those that were the least frequently answered: 1.7, 2.1-2.3, and 4.1 (see Table

1), and those that did not appear to be differently answered for non-invaders and major invaders: 1.2-6, 5.1, and 10.1-2. This analysis was conducted on the full U.S. region only and involved 97 species. Similar values for the accuracy and AUC would indicate that missing information for unanswered questions did not affect the overall discrimination capability of the survey and suggest the survey is robust to missing data. In other classification approaches, the AUC estimate was observed to significantly change when there were as little as 10% missing data (Markey et al. 2006).

Results

We were able to run the AqWRA on 127 of the 130 species for the U.S. test, with 2% of the species requiring further evaluation because they had ≥ 5 unanswered questions (Table 3, Figure 1). We found no relationship between the growth form of the aquatic species and the score (Figure 2). As anticipated, temperature tolerances automatically excluded additional species from the smaller regions; in particular, 46 species (36%) were determined to be unable to tolerate the cold temperatures of the Great Lakes region (Table 3). In contrast, only *Typha* x *glauca* was intolerant of Florida's climate. As a result, the sample size used for the Florida analyses was similar to that for the U.S. (125), while fewer species were available for the Great Lakes analyses (83). However, over all analyses, only 1-3% of the species could not be included because of missing information (Table 3).

Results for all species and regions are in Table 4. When non-invaders and major invaders are assessed for the U.S., the classification analysis reveals that overall accuracy is maximized with a threshold of 32 (i.e., species with scores lower than or equal to 32 were predicted as 'non-invaders', while species with scores over 32 were predicted to be 'major invaders'). The combined accuracy for both groups is 97% (Figure 3). Using this threshold an equal proportion of the minor invaders would be concluded to be non-invasive as invasive. The AUC, when the ability of the tool to distinguish non-invaders from minor and major invaders is tested, is 0.93 (Figure 4); when minor invaders are included as non-invaders and tested against the major invaders, the AUC is 0.96. In either case, the model distinguishes well between non-invaders and invaders.

All species scoring 60 or higher in the U.S. dataset are major invaders (Figure 3A). Species with scores between 32 and 60 were almost exclusively either minor or major invaders (2 non-invaders). This range can be further differentiated: 95 % (37/39) of the major invaders had scores of 40 and above, while 16% (5/32) of minor invaders fell in that score range. Thus, species with scores of 33-39 are more likely to be minor invaders, while those with higher scores are likely to be major invaders.

Accuracy for the smaller regional tests was lower than for the U.S. (Figure 5A, B). Maintaining the threshold of 32 for the Great Lakes region results in 84% overall accuracy, with 100%

accuracy in identifying the major invaders and over 85% accuracy in identifying the non-invaders. For this region, roughly 80% of the minor invaders would be identified as having a high probability of becoming invasive. The AUC when minor and major invaders are combined is 0.90 (AUC = 0.93 for minor invaders considered non-invaders). For Florida, the accuracy decreases in part because data from Florida were excluded from the analysis. Overall accuracy is 77%, with over 95% of the major invaders, and 70% of non-invaders identified correctly. Roughly 60% of the minor invaders would have been predicted to become invasive. The AUC values are 0.82 and 0.91 when minor invaders are classified as invaders and non-invader, respectively. The accuracy is the same as found for the AWRA for terrestrial plants (Gordon et al. 2008), with the exception that fewer species require further evaluation (10% for AWRA versus 2% for the AqWRA; note the methods for determining species in this category are different between the risk assessment systems).

When all combinations of removing the 13 questions that were either infrequently answered (1.7, 2.1-2.3, and 4.1) or answered similarly for non- and major invaders (1.2-6, 5.1, 10.1-2) were compared to the full model, we found minimal changes in accuracy (Table 6). Individually removed, only question 5.1 resulted in any change in accuracy, from 97% in the full model to 96% with the question removed (Table 6). This assessment did not include the minor invaders (n=97), resulting in higher AUC for both the full and the partial models than the full model run with all species (n=127). For all runs, the AUC remained at 0.99, suggesting that the results of the predictive tool are not sensitive to removal of these questions. As anticipated, the threshold scores distinguishing non-invaders from invaders decreased because the points contributed by the questions removed were also removed. Some combinations resulted in multiple thresholds with the same accuracy.

All 20 validation species were correctly identified as invasive or non-invasive in the U.S. (Table 7). While the sample size for this validation exercise was relatively small, the results support both the utility of the model and the accuracy of the empirically derived threshold score. Further evaluation of more species would give more insight into the performance of the AqWRA.

Discussion

The AqWRA modified from the New Zealand system (Champion and Clayton 2000) distinguished between non-invaders and major invaders with equally high accuracy: 97%. This tool is clearly more sensitive and accurate for freshwater macrophytes than is the AWRA (Gordon and Gantz 2011). Not only was accuracy high for these groups and all growth forms, but only 1-3% of the species required further evaluation (> 4 unanswered questions). Thus, the tool substantially exceeds the accuracy standard of 80% set in Objective 1 for this research.

Using the U.S. dataset and including scores from all the questions (Table 1), species with scores of 32 and below are predicted to have a low probability of invading 97% of the time. Species with scores above 60 are all major invaders (Figure 3A); additionally our data suggest that most minor invaders will have scores ranging from 33 to 39, while most major invaders will have scores of 40 and above. Those minor invaders with higher scores may have a higher probability of becoming more invasive over time, and should be watched. These cut-offs cannot be compared to those determined for use in New Zealand or other locations, because of differences in questions and scoring in the AqWRA (Champion and Clayton 2000, Champion et al. 2008).

The AqWRA was generally more accurate at the national level than at the regional level. Additionally, the accuracy was lower for the Florida test than the Great Lakes test. This difference is partially explained both because we excluded data from a species within a region for the regional test (e.g., *Luziola subintegra* is currently only known to be invasive in Florida. Those data could not be used in the Florida test, where the species was determined to be of low risk for invasion (score=18), but could be used in the Great Lakes test (score=37).), and because the colder temperatures in the Great Lakes excluded a number of species that might otherwise have been high-scoring non-invaders. The larger range of temperatures across the U.S. precluded these more local effects. However, where much of the data on invasiveness is from areas within the U.S. but outside Florida or the Great Lakes, the regional assessments were more accurate than the national one (e.g., *Murdannia keisak*).

However, despite the lower accuracy for non-invaders in the regional tests of the tool for Florida and the Great Lakes, the accuracy found is either greater than or equivalent to the accuracy of the AWRA for terrestrial species (Gordon et al. 2008) and had consistently higher accuracy for aquatic plant species (Gordon and Gantz 2011). As described above, an accuracy level in excess of 75% has both been accepted by several governments, and been demonstrated to be a cost-effective approach in Australia (Keller et al. 2007).

At the regional level, the AqWRA could be used to identify species that should be regulated by states to prevent spread and impacts. However, prevention of new species with a high probability of invading is more effective at international borders because restrictions on post-importation interstate movement of species are limited and difficult to enforce. Within the U.S., application of the AqWRAat state or basin scales might better be employed to help identify management priorities. The preliminary screening of temperature tolerance employed at the regional level (Table 1, Question 1.1) would speed this assessment. Australia differentiates between these two approaches as weed risk assessment (pre-border) and weed risk management (Ferdinands et al. 2011).

We used 30 years as the time-frame in which species are likely to become naturalized (Champion et al. 2008). However, year of introduction does vary among the *a priori* classification of species: of the 30 test species in this dataset introduced since 1960, 25 were non-invaders (42% of the total number in this category), 3 (10%) were minor invaders (*Houttuynia* *cordata*, *Hygrophila difformis*, and *Limnophila indica*), and 2 (5%) were major invaders (*Hymenachne amplexicaulis* and *Rotala rotundifolia*). Seven of the twenty validation species were also introduced within the last 30 years and three of these are invasive (*Glyceria declinata*, *Ludwigia grandiflora* subsp. *hexapetala,* and *Rorippa amphibia*). Most of the scores correspond to these ratings, but any species introduced in this period that have scores above 32 (e.g., *Hydrocotyle vulgaris)* may warrant management now to preclude future invasion (see below).

Although our dataset included fewer invaders than non-invaders, actual proportion of all introduced species likely to become invasive is even lower (Williamson and Fitter 1996). The equivalent AqWRA accuracy in distinguishing non-invaders from invaders suggests no bias that might otherwise be caused by the prevalence of non-invaders versus invaders in the dataset. Additionally, the high AUC in the ROC analysis, which is independent of the proportion in either category (Smith et al. 1999), provides greater confidence in this model.

The removal of 13 questions from the AqWRA neither reduced the accuracy of the discrimination (97%), nor the robustness of the evaluation (AUC=0.99). This result suggests that partial completion of the assessment or a reduced form of the assessment may be sufficient to conduct a reliable risk evaluation for aquatic invasive plants. For screening of unprecedented species in the U.S., this result is particularly critical since species under evaluation may be relatively unstudied, resulting in limited availability in the literature of information needed to perform the risk assessment. Fewer questions in a tool that still provides robust discrimination between non-invaders and major invaders would be advantageous. This is an area of further research and development.

AqWRA use for management decisions

Use of the AqWRA as a preventative tool for screening proposed new aquatic plant imports into the U.S. appears to be beneficial. This tool may also provide guidance for setting management priorities, as is done in New Zealand (Champion and Clayton 2001b). While the scores are dependent on the data available and should not be used literally to rank individual species, we are able to make some recommendations based on the scores and other information.

1) Any species with a score of 60 or higher is worth managing unless its distribution and management potential suggest that control efforts would either be unsuccessful or so costly that the resources would better be allocated to another species.
2) Proactively control species with scores above 32 that have been introduced recently, perhaps defining recent as within the last 30 years as aquatic species may express their invasiveness rapidly on average relative to terrestrial species (Gordon and Gantz 2011). We fairly arbitrarily suggest 30 years as encompassing the several years it first takes for naturalization of a new species to be noticed, followed by several years for collection and synthesis of abundance and impacts information about that species. These recent invaders

may be the group most successfully eradicated as they may still be at low population levels. *Luziola subintegra* may be an example of this type of species; while its score is not high (37), it has only recently been discovered in the U.S. (Kunzer and Bodle 2008), has no history of introduction elsewhere, and is already a recognized problem in Florida.

3) Also prioritize species that are currently minor invaders in the U.S. but are highly invasive in other countries for management, regardless of how long they have been in the U.S. For example, *Hydrocleys nymphoides* (score = 46) has been in the U.S. for over a century (Tricker 1897) and is currently a minor invader in Texas and Florida (Haynes 2000, http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=222000085.). However, its invasive behavior in New Zealand and Australia (Environment Waikato 2010) suggest that it might be become more invasive in the U.S. as well (i.e., a “sleeper weed” *sensu* Groves 2006).
4) When selecting among species for control, look also at the climate tolerances and potential for spread. If a species survives in a wide range of U.S. Department of Agriculture Hardiness Zones (e.g., 1-11) but is currently present in only a few of those zones, control priority should be high. For example, *Rorippa amphibia* is documented in at least seven (3-9) Hardiness Zones globally (NAPPFAST 2007, National Vegetation Data Bank 2011), but is currently found in only 3 of those zones (5-7) in the U.S. (NAPPFAST 2007, University of Connecticut 2011, USDA NRCS 2011). The AqWRA score of 35 might suggest that this species is a low priority for management, but the potential for spread would support a more aggressive management approach. *Cyperus serotinus* occupies Zones 4-11 outside of the U.S., but is only recorded in Zones 6-7 in the U.S. (Real Jardín Botánico, CSIC Fundación Biodiversidad 2006; NAPPFAST 2007). Its low score of 26 may underestimate the potential future distribution of this species.
5) Lastly, where possible, prioritize any species that is naturalized with a score above 32 that can be controlled easily and inexpensively. Because some minor invaders may be sleeper weeds and eradication of small populations is the most cost-effective approach, we recommend erring on an aggressive control approach if resources exist. This pro-active approach may be most critical in systems with biodiversity or ecosystem services vulnerable to impacts of aquatic plants. As our expertise is not in control efforts, we will leave examples of this consideration to others.

These recommendations should be interpreted within a larger context than we can incorporate here. The AqWRA score alone should not define the management priority. The scores should be used to prioritize allocation of effort among species assuming all other considerations are equal (Table 8). Long-term control success, feasibility and expense of control efforts should clearly influence final resource allocation decisions, as should the vulnerability and irreplaceability (*sensu* Margules and Pressey 2000) of the biodiversity or economic assets in the waterway threatened.

The AqWRA confirms that all the non-native aquatic macrophytes currently under management within Army Corps of Engineers Projects (J. Spencer 2011, pers. comm.) have a high probability of becoming invasive (Appendix B). However, we have identified species predicted to be invasive that are currently not controlled. While we suspect this is because the species are not present on ACOE projects, we suggest that project managers be queried about presence of some of these species that should receive management priority if resources are available. These species should also be priorities for early detection monitoring programs within ACOE sites.

Currently, only five of the twenty-six species we predict have the highest probability of being invasive in the U.S. (scores > 60) are regulated by the U.S. Department of Agriculture as Noxious Weeds (Table 8; http://www.aphis.usda.gov/plant_health/plant_pest_info_weeds/ downloads/ weedlist-2010doc.pdf). An additional two species with scores above 39, two species with scores of 33-39, and one species with a score of 30 (*Sagittaria sagittifolia* subsp. *leucopetala*; the full species is listed) are federally listed. When all species with scores of 40 and above are considered, 44 species likely to cause economic and ecological harm to the U.S. should be evaluated for federal listing as Noxious Weeds.

While more testing with additional species would increase our confidence in the AqWRA, the high accuracy of this tool suggests it is appropriate for both prevention and management decisions. Accuracy of the current risk assessment system used by USDA-APHIS-PPQ-CPHST-PERAL should be compared against the AqWRA for freshwater macrophytes. Although the PERAL system has improved on the accuracy of the AWRA (A. Koop 2011, pers. comm.), because the PERAL approach is based on the AWRA, it may share insufficient consideration of traits specific to aquatic plants. Regardless of the risk assessment system, the high accuracy with which we can distinguish non-invaders from harmful invaders at the U.S. scale suggests that a more pro-active prevention system would be both feasible and cost-effective.

Acknowledgements

This work was completed in collaboration with Christopher Jerde, who conducted the statistical analyses, Lindsay Chadderton, Paul Champion, and Reuben Keller. We appreciate the assistance of J. Gardina and J. Chase with literature review. D. Keller, E. Elgin, J. Chase, R. Keller, J. Schardt, D. Schmitz, and R. Weaver helped with identification of aquatic plant species. Funding from the Florida Fish and Wildlife Conservation Commission and the Florida and Michigan Chapters of The Nature Conservancy also supported portions of this work.

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Table 1. The Aquatic Weed Risk Assessment Tool (AqWRA). The question numbers correspond with those in the worksheet that is used to assess each species. Possible score range appears in bold prior to more specific guidance on the points associated with different responses in the scoring guidance for addressing each question. Questions and scores are modified from Champion and Clayton (2000, 2001) and Champion (pers. comm.). See Appendix A for more information.

Question	Scoring Guidance
Temperature tolerance (1.1)	**(0-3)** Should be modified for the region of interest. Modifications for this analysis: Great Lakes Test: **(0-3)** 3 if maintains photosynthetic tissue and summer growth form throughout winter, 2 if dies back to tuber/bulb/rhizome (or similar structure) during winter, 1 if adult plants completely die but viable seeds remain (consider with 'hardiness zone' question in regional screen). 0 if the species is extirpated by summer or winter temperatures. Florida Test: **(0-3)** 3 if maintains photosynthetic tissue and summer growth form throughout summer, 2 if dies back to tuber/bulb/rhizome (or similar structure) during summer, 1 if adult plants completely die but viable seeds remain (consider with 'hardiness zone' question in regional screen). 0 if the species is extirpated by summer temperatures. United States Test: **(0-3)** 3 if maintains photosynthetic tissue and summer growth form throughout winter, 2 if dies back to tuber/bulb/rhizome (or similar structure) during winter, 1 if adult plants completely die but viable seeds remain (consider with 'hardiness zone' question in regional screen). 0 if the species is extirpated by summer or winter temperatures. Default to 1 for annual species.
Range of habitat (1.2)	**(1-3)** Score 3 if able to grow from water to dry land, 2 if water to wetland, or from shallow to deep (>5 m) water, 1 narrow range. Default = 1 if no information is available; 2 for free-floating plants, unless more information is available.
Water/substrate type tolerance (1.3)	**(1-2)** Score 2 if tolerant of sandy to muddy (or peaty) substrate, or oligotrophic to eutrophic waters, 1 if restricted by either. Default = 1 if no information is available.
Water clarity tolerance (1.4)	**(0-1)** Score 1 if unaffected by water clarity (i.e. floating or emergent, or submergents tolerant of very low light levels, such as *Myriophyllum spicatum* and *Hydrilla verticillata*). 0 if affected by water clarity.
Salinity tolerance (1.5)	**(0-1)** Score 1 if species can tolerate saline conditions, 0 if not. Habitat information can be used to determine a score of 0 if species is only found to occur in freshwater habitats.
pH tolerance (1.6)	**(0-1)** Score 1 if tolerant of both acidic and basic pH or no information is available, 0 if restricted to neutral, basic, or acidic pH.

Water level fluctuation - Tolerates periodic flooding/drying (1.7)	**(0-3)** Score 3 for species which have evidence of tolerating periodic flooding/drying with a specified time period longer than 1 month (e.g., "months"; "X months", "winter flooding"), 2 for evidence of tolerance of flooding/drying over a period of days/a couple of weeks, 1 for species that die back during periods of flooding/drying, and 0 for species that do not tolerate flooding/drying. Do not score if there is no information available.
Lentic - rivers, streams, drains, or other flowing waters, including their margins (2.1)	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.
Ponds, lakes and other standing waters, including their margins (2.2)	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.
Swamp, marsh, bog, or other wet areas not covered by 2.1 or 2.2 (2.3)	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed, 1 if present but not weedy, 0 if absent.
Establishment – into existing vegetation (2.4)	**(-5 to 0)** Score 0 if able to invade unmodified vegetation, -3 if the species can only colonize certain types of vegetation (e.g., turf-forming shoreline vegetation), -5 if there is no evidence that the species can move into intact vegetation. Default = 0 if there is evidence of establishment, but no specific information about level of invasion into existing vegetation and/or type of vegetation being invaded. Default = -3 for species that have not naturalized outside of their native range.
Establishment – into disturbed vegetation (2.5)	**(0 to 5)** Score 5 if able to aggressively colonize following vegetation clearance, newly constructed waterbodies or nutrient enrichment, 1 if the species grows in disturbed areas, but there is no other information, 0 if there is no evidence of establishment in disturbed areas. Information from either the native or introduced range may be used to answer this question. Default = 1 for no information.
Competition – between growth form (3.1)	**(0, 1, 2)** Score 2 if species forms dense stands that are documented to displace other growth forms (submerged, floating, emergent), 1 if some suppression, 0 if no displacement. Default = 0 if species has been in the trade globally for >30 years and there is no information about the species displacing other growth forms.
Dispersal outside catchment by natural agents, e.g. birds, wind (4.1)	**(0, 1, 3, 5)** Score 5 if species (including seeds, rhizomes, fragments etc.) well adapted, and likely to be frequently dispersed, by natural agents, 3 if transport by natural agents is possible but uncommon, 1 if propagule could be spread in bird crop, 0 if no, or extremely low, likelihood of dispersal by natural agents (e.g., Hydrilla is scored 1 because its turions can survive passage through duck guts, an agent of dispersal, but this is believed to happen rarely).
Dispersal outside catchment by accidental human activity	**(1, 2, 3)** Score 3 major pathway, seeds/fragments adapted for easy transportation (e.g., via boat/trailer, fishing gear), 2 if the species is a floating plant or a macrophyte, but no explicit mention of high spread in the literature,

(4.2)	1 not mentioned, not likely to be spread by human activity based on growth form and life history. Default = 1 if no information is available.
Dispersal outside catchment by deliberate introduction (4.3)	**(0-1)** Score 1 if species is desirable to humans (e.g., or used for medicinal, food, ornamental, restoration, etc. purposes in the U.S. or elsewhere). If species is not used or no information exists, it should be scored a 0.
Effective spread within waterbody/ catchment (4.4)	**(0-1)** Score 1 for extensive spread within a waterbody or among waterbodies, 0 for no spread. Occurrence along stream or riverbanks or in rivers can be used as evidence, as well as evidence of water dispersal. Do not answer if there is no information available.
Generation time - Includes growth rate and time to maturity under ideal conditions. (5.1)	**(1, 2, 3)** Score 3 if rapid (reproduction in first year and >1 generation/year), 2 if annual or produces one generation every year including the first year, 1 if not reproductively mature in the first year. Default = 1 if no information is available.
Seeding ability - Quantity (6.1)	**(0-3)** Score 3 if >1000 seeds/plant/year, 2 100-1000, 1 <100 and/or evidence that seed are produced (in native or introduced range), 0 if seed not produced.
Seeding ability - Viability/persistence (6.2)	**(0-2)** Score 2 if highly viable for >3 years, 1 low viability or evidence of seed production with no information on viability, 0 no viable seeds.
Vegetative reproduction (7.1)	**(0, 1, 3, 5)** Score 5 for naturally fragmenting from rhizomes, stolons, or other vegetative growth into tissue capable of producing new colonies (e.g., *Egeria densa*), 3 if produces rhizomes/stolons, but there is no other information about the formation of new colonies elsewhere, 1 for clump-forming by vegetative spread, 0 for no vegetative spread.
Physical - water use (recreation) (8.1)	**(0-2)** Score 2 for major nuisance, 1 minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.
Physical – access (8.2)	**(0-2)** Score 2 for major nuisance, 1 minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.
Physical - water flow, power generation (8.3)	**(0-2)** Score 2 for major nuisance, 1 minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.
Physical - irrigation, flood control (8.4)	**(0-2)** Score 2 for major nuisance, 1 minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.
Aesthetic - visual, olfactory	**(0-2)**. Score 2 for both visual and odor problems, 1 either, 0 neither or no mention of these impacts. Surface

(8.5)	matting of macrophytes scores 1 for visual impact.
Reduces biodiversity (9.1)	**(0, 1, 3, 5)** Score 5 for extensive monospecific stands, 3 for species that become dominant, 1 for small monospecific stands, and 0 if species does not become dominant over other species. Default = 0 if species has been in the trade globally for >30 years and there is no information found or if the species is not naturalized outside of its native range.
Reduces water quality (9.2)	**(0, 1, 3)**. Score 3 if evidence that this species causes deoxygenation (e.g., through extensive growth in shallow water) or other water quality loss (e.g., loss of water clarity because of high decomposition rates continuously during the growing season), 1 if deoxygenation or other water quality loss is likely based on seasonal growth cycles (e.g., macrophyte that gets to high density and dies off at end of summer), 0 otherwise. Default = 0 if species has been in the trade globally for >30 years and there is no information found.
Negatively effects physical processes (9.3)	**(0, 2)**. Score 2 if species alters hydrology (e.g., increases the chance of flooding) or substrate stability (e.g., increases amount of sediment erosion or deposition), or other physical processes, 0 if the species has no history of modifying physical processes. Default = 0 if species has been in the trade globally for >30 years and there is no information found.
Health impairment, e.g. drowning, poisonous, sharp leaf edges, mosquito breeding habitat (10.1)	**(0-2)** Score 1 for one effect, 2 for 2 or more effects.
Weed of agriculture, including crops, livestock and aquaculture (10.2)	**(0-1)** Score 1 if a problem agricultural weed, 0 if no evidence that it is an agricultural weed, or if evidence states that species is in agricultural areas but not problematic.
Management - Ease of management implementation (11.1)	**(0-2)** Score 2 if accessibility to weed is difficult, e.g. dense tall impenetrable growths or growing in habitats that are difficult to access by roads or waterways (e.g., swamps). For species that have naturalized outside of their native range, default to a score between 0-2 based upon evidence about habitat and/or growth form if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.

Management - Recognition of management problem (11.2)	**(0-1)** Score 1 if difficult to assess weed, e.g. submerged; looks like another species. For species that have naturalized outside of their native range, default to a score between 0-1 based upon growth form evidence if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Management - Scope of control methods (11.3)	**(0-2)** Score 2 if no control method, 1 if only one control option. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Management - Control method suitability (11.4)	**(0-1)** Score 2 if control method not always acceptable, e.g. grass carp, unregistered herbicide. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Management - Effectiveness of control (11.5)	**(0-2)** Score 2 if ineffective, 1 if partial control. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2. Default = 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Management - Duration of control (11.6)	**(0-2)** Score 2 if no control, 1 if control for 3+ months. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Problem in other countries (12.1)	**(0, 1, 3, 4, 5)** Score 5 if species has been reported to be a widespread problem (i.e., a harmful weed in many other countries), 4 if species has been reported to be a harmful weed in 5 or fewer countries, 3 if species has been reported to be a widespread adventive (but not a harmful weed) in many other countries, 1 if species has been reported to be adventive in 5 or fewer countries,0 if not adventive elsewhere.

Table 2. Species assessed in development of the model. All species are not native to the U.S. and have been introduced to the U.S. before 1981. The introduction dates listed represent the first date earlier than 1980 that we identified, rather than the actual date of introduction.

Scientific Name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Acorus calamus L.	Sweet-flag	Acoraceae	Erect emergent	1897	1897
Acorus gramineus Sol. ex Aiton	Grass-leaf sweet-flag	Acoraceae	Sprawling emergent*	1897	1897
Aldrovanda vesiculosa L.	Waterwheel plant	Droseraceae	Free-floating	1967	1947
Alisma plantago-aquatica L.	Water-plantain	Alismataceae	Erect emergent	1897	1897
Alternanthera philoxeroides (Mart.) Griseb.	Alligator-weed	Amaranthaceae	Sprawling emergent	1928	1928
Alternanthera sessilis (L.) R. Br. ex DC.	Sessile joyweed	Amaranthaceae	Sprawling emergent	1945	1945
Ammannia senegalensis Lam.**	Red ammannia	Lythraceae	Erect emergent; submerged*	1959	1959
Anubias afzelii Schott	Afzeli anubias	Araceae	Amphibious submerged*	1976	1960
Anubias barteri Schott	Giant anubias	Araceae	Amphibious submerged*	1959	1959
Anubias barteri var. *glabra* N.E. Br.	Anubias	Araceae	Amphibious submerged*	1959	1959
Aponogeton crispus Thunb.	Ruffled sword plant	Aponogetonaceae	Submerged*	1967	1932
Aponogeton distachyos L. f.	Cape-pondweed	Aponogetonaceae	Water lily type (attached-floating)	1897	1897
Aponogeton madagascariensis (Mirb.) H. Bruggen	Laceleaf	Aponogetonaceae	Erect emergent; submerged*	1855	1855
Aponogeton natans (L.) Engl. & Krause	Floating lace plant	Aponogetonaceae	Erect emergent; submerged*	1967	1947
Aponogeton ulvaceus Baker	Compact aponogeton	Aponogetonaceae	Submerged	1967	1947

Scientific Name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Barclaya longifolia Wall. (=*Hydrostemma longifolium* (Wall.) Mabb.)	Orchid lily	Nymphaeaceae	Submerged	1967	1958
Bolbitis heteroclita (C. Presl) Ching	Asian water fern	Lomariopsidaceae	Amphibious submerged*	1959	1959
Bolbitis heudelotii (Bory ex Fée) Alston	African water fern	Lomariopsidaceae	Amphibious submerged*	1977	1960
Butomus umbellatus L.	Flowering-rush	Butomaceae	Erect emergent	1897	1897
Callitriche stagnalis Scop. emend. Kutz	European water-starwort	Callitrichaceae	Attached-floating; amphibious submerged; sprawling emergent	1861	1861
Canna × generalis L.H. Bailey & E.Z. Bailey	Common garden canna	Cannaceae	Erect emergent	1930	1930
Canna indica L.	Edible canna	Cannaceae	Erect emergent	1947	1947
Cardamine lyrata Bunge	Chinese-ivy	Brassicaceae	Amphibious submerged; sprawling emergent*	1967	1947
Ceratophyllum muricatum subsp. *australe* (Griseb.) Les	Prickly hornwort	Ceratophyllaceae	Submerged	1950	1950
Ceratophyllum submersum L.**	Soft hornwort	Ceratophyllaceae	Submerged	1967	1947
Colocasia esculenta (L.) Schott	Taro	Araceae	Erect emergent	1905	1905
Colysis pteropus (Blume) Bosman (=*Microsorum pteropus* (Blume) Copel.)	Java fern	Polypodiaceae	Amphibious submerged*	1929	1929
Crinum erubescens Aiton	Swamp lily	Amaryllidaceae	Erect emergent	1949	1949
Cryptocoryne × willisii Reitz	Willis' cryptocoryne	Araceae	Amphibious submerged*	1949	1949

Scientific Name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Cryptocoryne ciliata (Roxb.) Fisch. ex Wydl.	Ciliata	Araceae	Amphibious submerged*	1967	1947
Cryptocoryne cordata Griff.	Cryptocoryne	Araceae	Amphibious submerged*	1967	1947
Cryptocoryne crispatula Engl.	Balansae crypto	Araceae	Amphibious submerged*	1967	1947
Cyperus difformis L.	Small-flower umbrella-plant	Cyperaceae	Erect emergent	1934	1934
Cyperus involucratus Rottb.	Umbrella sedge	Cyperaceae	Erect emergent	1909	1909
Cyperus longus L.	Sweet cyperus	Cyperaceae	Erect emergent	1901	1901
Cyperus prolifer Lam.	Dwarf papyrus	Cyperaceae	Erect emergent	1947	1947
Cyperus serotinus Rottb.	Tidal marsh flat sedge	Cyperaceae	Erect emergent	1935	1935
Echinodorus martii Micheli (=*Echinodorus major* (Micheli) Rataj)	Ruffled Amazon sword	Alismataceae	Erect emergent; submerged*	1967	1947
Echinodorus palaefolius (Nees & Mart.) J.F. Macbr.	Mexican sword-plant	Alismataceae	Erect emergent*	1959	1959
Echinodorus paniculatus Micheli	Amazon sword-plant	Alismataceae	Erect emergent; submerged*	1967	1947
Echinodorus uruguayensis Arechav.	Uruguay Amazon sword	Alismataceae	Erect emergent; submerged*	1950	1950
Egeria densa Planch.	Brazilian elodea	Hydrocharitaceae	Submerged	1893	1893
Eichhornia azurea (Sw.) Kunth	Anchored water-hyacinth	Pontederiaceae	Attached-floating; obligate submerged; water-lily type	1897	1897
Eichhornia crassipes (Mart.) Solms	Water-hyacinth	Pontederiaceae	Free-floating	1897	1897
Eichhornia paniculata (Spreng.) Solms	Brazilian water hyacinth	Pontederiaceae	Erect emergent	1913	1913
Elatine macropoda Guss.	Southern waterwort	Elatinaceae	Submerged	1967	1947

Scientific Name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Eriophorum latifolium Hoppe	Grey cotton-grass	Cyperaceae	Erect emergent	1949	1949
Euryale ferox Salisb. ex K.D. Koenig & Sims	Gorgon	Nymphaeaceae	Water lily type (attached-floating)	1897	1897
Glyceria fluitans (L.) R. Br.	Floating manna grass	Poaceae	Sprawling emergent	1930	1930
Glyceria maxima (Hartm.) Holmb.	Reed sweet grass	Poaceae	Sprawling emergent	1940	1940
Gratiola officinalis L.	Gratiola	Plantaginaceae	Erect emergent; sprawling emergent	1930	1930
Gratiola peruviana L.	Austral brooklime	Plantaginaceae	Erect emergent	1833	1833
Hesperantha coccinea (Backh. & Harv.) Goldblatt & J.C. Manning (=*Schizostylis coccinea* Backh. & Harv.)	River-lily	Iridaceae	Erect emergent	1930	1901
Heteranthera zosterifolia Mart.	Stargrass	Pontederiaceae	Erect emergent; submerged*	1967	1932
Hottonia palustris L.	Water-violet	Primulaceae	Submerged	1897	1901
Houttuynia cordata Thunb.	Chameleon-plant	Saururaceae	Erect emergent	1976	1947
Hydrilla verticillata (L. f.) Royle	Hydrilla	Hydrocharitaceae	Submerged	1959	1959
Hydrocharis morsus-ranae L.	European frog's-bit	Hydrocharitaceae	Free-floating	1897	1897
Hydrocleys nymphoides (Willd.) Buchenau	Water-poppy	Limnocharitaceae	Attached-floating	1897	1897
Hydrocotyle vulgaris L.	Marsh pennywort	Araliaceae	Sprawling emergent*	1967	1947
Hygrophila corymbosa Lindau**	Giant hygrophila	Acanthaceae	Erect emergent*	1917	1917
Hygrophila difformis (L.f.) Blume	Water-wisteria	Acanthaceae	Erect emergent; submerged*	1967	1957
Hygrophila polysperma (Roxb.) T. Anderson	Indian swampweed	Acanthaceae	Erect emergent*	1947	1947

Scientific Name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Hymenachne amplexicaulis (Rudge) Nees	West Indian marsh grass	Poaceae	Sprawling emergent	1968	1968
Ipomoea aquatica Forssk.	Chinese water-spinach	Convolvulaceae	Free-floating; sprawling emergent	1949	1949
Iris ensata Thunb.	Japanese water iris	Iridaceae	Erect emergent	1897	1897
Iris pseudacorus L.	Yellow-flag iris	Iridaceae	Erect emergent	1868	1868
Landoltia punctata (G. Mey.) Les & D.J. Crawford	Dotted duckmeat	Araceae	Free-floating	1930	1930
Lasia spinosa (L.) Thwaites	Lasia	Araceae	Erect emergent	1959	1959
Lilaeopsis novae-zelandiae A.W. Hill	Micro sword	Apiaceae	Amphibious submerged*	1979	1979
Limnocharis flava (L.) Buchenau	Sawah-flower rush	Limnocharitaceae	Free-floating	1934	1934
Limnophila indica (L.) Druce	Ambulia	Limnocharitaceae	Amphibious submerged*	1967	1947
Limnophila sessiliflora (Vahl) Blume	Ambulia	Limnocharitaceae	Amphibious submerged*	1961	1947
Ludwigia adscendens (L.) H. Hara	Water-primrose	Onagraceae	Sprawling emergent	1979	1947
Ludwigia helminthorrhiza (Mart.) H. Hara	Rattlebox	Onagraceae	Free-floating*	1976	1917
Ludwigia peruviana (L.) H. Hara	Peruvian primrosebush	Onagraceae	Sprawling emergent*	1929	1929
Lythrum salicaria L.	Purple loosestrife	Lythraceae	Erect emergent	1831	1831
Marsilea drummondii A. Braun	Common nardoo	Marsileaceae	Attached-floating*	1949	1947
Marsilea quadrifolia L.	European water-clover	Marsileaceae	Attached-floating*	1860	1860
Mentha aquatica L.	Water mint	Lamiaceae	Sprawling emergent*	1933	1898
Murdannia keisak (Hassk.) Hand.-Mazz.	Marsh dewflower	Commelinaceae	Sprawling emergent*	1935	1935

Scientific Name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Myosotis scorpioides L.	Forget-me-not	Boraginaceae	Sprawling emergent	1886	1886
Myriophyllum aquaticum (Vell.) Verdc.	Parrot's-feather	Haloragaceae	Sprawling emergent*	1890	1890
Myriophyllum spicatum L.	Eurasian water-milfoil	Haloragaceae	Submerged	1905	1905
Najas minor All.	Brittle naiad	Najadaceae	Submerged	1932	1932
Nasturtium microphyllum Boenn. ex Rchb.	One-row watercress	Brassicaceae	Attached-floating; sprawling emergent	1946	1946
Nasturtium officinale R. Br.	Watercress	Brassicaceae	Sprawling emergent	1831	1831
Nechamandra alternifolia (Roxb.) Thwaites	Nechamandra	Hydrocharitaceae	Submerged	1970	1947
Nelumbo nucifera Gaertn.	East Indian lotus	Nelumbonaceae	Water lily type (attached-floating)	1897	1897
Nymphaea × daubenyana W.T. Baxter ex Daubeny	Dauben's waterlily	Nymphaeaceae	Water lily type (attached-floating)	1934	1932
Nymphaea candida C. Presl	Hardy waterlily	Nymphaeaceae	Water lily type (attached-floating)	1897	1897
Nymphaea capensis Thunb. (=*Nymphaea capensis var. zanzibariensis* Conard)	Cape blue water-lily	Nymphaeaceae	Water lily type (attached-floating)	1897	1897
Nymphaea colorata Peter.	Blue pygmy	Nymphaeaceae	Water lily type (attached-floating)	1940	1947
Nymphaea lotus L.	Egyptian lotus	Nymphaeaceae	Water lily type (attached-floating)	1897	1897
Nymphoides crenata (F. Muell.) Kuntze	Wavy marshwort	Menyanthaceae	Water lily type (attached-floating)	1917	1917
Nymphoides indica (L.) Kuntze	Water-snowflake	Menyanthaceae	Attached-floating; free-floating	1897	1897
Nymphoides peltata (S.G. Gmel.) Kuntze	Yellow floating-heart	Menyanthaceae	Attached-floating	1863	1863

Scientific Name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Oenanthe aquatica (L.) Poir.	Fine-leaf water-dropwort	Apiaceae	Sprawling emergent	1836	1836
Ottelia alismoides (L.) Pers.	Duck-lettuce	Hydrocharitaceae	Submerged	1939	1939
Panicum repens L.	Torpedograss	Poaceae	Sprawling emergent	1891	1891
Persicaria hydropiper (L.) Opiz (=*Polygonum hydropiper* L.)	Marsh-pepper smartweed	Polygonaceae	Erect emergent	1893	1893
Philydrum lanuginosum Banks & Sol. ex Gaertn.	Frogmouth	Philydraceae	Sprawling emergent	1847	1847
Pistia stratiotes L.	Water-lettuce	Araceae	Free-floating	1897	1897
Potamogeton crispus L.	Curly-leaf pondweed	Potamogetonaceae	Submerged	1860	1860
Potamogeton gayii A. Benn.	Slender pondweed	Potamogetonaceae	Submerged	1967	1960
Potamogeton wrightii Morong	Potamogeton	Potamogetonaceae	Submerged	1967	1947
Ranunculus lingua L.	Greater spearwort	Ranunculaceae	Erect emergent	1949	1901
Regnellidium diphyllum Lindm.	Two-Leaf water clover	Marsileaceae	Water lily type (attached-floating)	1941	1941
Ricciocarpos natans (L.) Corda	Purple-fringed riccia	Ricciaceae	Free-floating; sprawling emergent	1893	1893
Rotala rotundifolia (Buch.-Ham. ex Roxb.) Koehne	Roundleaf toothcup	Lythraceae	Amphibious submerged*	1967	1960
Sagittaria sagittifolia subsp. *leucopetala* (Miq.) Hartog	Chinese arrowhead	Alismataceae	Erect emergent	1905	1901
Salvinia minima Baker	Water spangles	Salviniaceae	Free-floating	1889	1889
Salvinia natans All.	Floating watermoss	Salviniaceae	Free-floating	1897	1897
Saururus chinensis (Lour.) Baill.	Chinese lizard's tail	Saururaceae	Erect emergent	1901	1901

Scientific Name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Schoenoplectus glaucus (Lam.) Kartesz (=*Bolboschoenus glaucus* (Lam.) S.G. Sm.)	Tuberous bulrush	Cyperaceae	Erect emergent	1923	1923
Schoenoplectus mucronatus (L.) Palla	Rice-field bulrush	Cyperaceae	Erect emergent	1899	1899
Trapa natans L.	European water-chestnut	Trapaceae	Free-floating	1874	1874
Typha × glauca Godr.	Cattail	Typhaceae	Erect emergent	1950	1950
Typha angustifolia L.	Narrow-leaf cattail	Typhaceae	Erect emergent	1880	1880
Typha minima Funck in Hoppe	Dwarf cattail	Typhaceae	Erect emergent	1897	1897
Urochloa mutica (Forssk.) T.Q. Nguyen	Para grass	Poaceae	Sprawling emergent	1889	1889
Utricularia aurea Lour.	Golden bladderwort	Lentibulariaceae	Free-floating*	1967	1947
Utricularia australis R. Br.	Bladderwort	Lentibulariaceae	Free-floating*	1905	1905
Vallisneria spiralis L.	Eel-grass	Hydrocharitaceae	Submerged	1905	1905
Veronica beccabunga L.	European brooklime	Plantaginaceae	Sprawling emergent	1876	1876
Vesicularia dubyana (Müll. Hal.) Broth.	Java moss	Hypnaceae	Submerged	1967	1960
Victoria amazonica (Poepp.) J.C. Sowerby	Amazon water-lily	Nymphaeaceae	Water lily type (attached-floating)	1897	1897
Victoria cruziana A.D. Orb.	Santa Cruz water-lily	Nymphaeaceae	Water lily type (attached-floating)	1905	1905
Wolffia welwitschii Hegelm.	Pond bogmat	Araceae	Free-floating	1974	1974

*Species are also grown as submerged plants in the aquarium trade.

**Species were not included in the analysis or results reported because > 4 questions were unanswered. These species require further evaluation.

Table 3. Total numbers of species in each *a priori* invasiveness category used for each regional test of the AqWRA.

	U.S.	**Florida**	**Great Lakes**
Non-invaders	60	86	91
Minor Invaders	31	24	23
Major Invaders	39	20	16
Total	130	130	130
Species needing further evaluation	3 (2%)	4 (3%)	1 (1%)
Species intolerant of regional climate	0	1	46
Total # species used in AqWRA development	**127**	**125**	**83**

Table 4. Validation species assessed to test the model. Half of the species were classified as invasive, half as non-invasive (see Table 2 for more information and Table 7 for *a priori* classifications).

Scientific name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Azolla pinnata subsp. *asiatica* R.M.K. Saunders & K. Fowler	Mosquito fern	Azollaceae	Free-floating	2007	1999
Glossostigma cleistanthum W.R. Barker	Mudmat	Phrymaceae	Submerged; sprawling emergent	1991	1991
Glyceria declinata Bréb.	Waxy mannagrass	Poaceae	Sprawling emergent	1947	1947
Ludwigia grandiflora subsp. *hexapetala* (Hook. & Arn.) G.L. Nesom & Kartesz	Water-primrose	Onagraceae	Erect emergent; sprawling emergent	“decades”	“decades”*
Luziola subintegra Swallen	Tropical American watergrass	Poaceae	Sprawling emergent	2007	2007
Marsilea minuta L.	Small water-clover	Marsileaceae	Erect emergent; sprawling emergent	1992	1992
Marsilea mutica Mett.	Australian water-clover	Marsileaceae	Erect emergent; sprawling emergent	1997	1947
Nymphoides cristata (Roxb.) Kuntze	Crested floating heart	Menyanthaceae	Attached-floating	1988	1982
Rorippa amphibia (L.) Besser	Great yellow-cress	Brassicaceae	Erect emergent; submerged	1950	1950
Salvinia molesta D.S. Mitch.	Giant salvinia	Salviniaceae	Free-floating	1983	1983
Blyxa japonica (Miq.) Maxim. ex Asch. & Gürke	Blyxa	Hydrocharitaceae	Submerged	1967	1967
Cabomba aquatica Aubl.	Giant cabomba	Cabombaceae	Submerged	1967	1932
Elatine alsinastrum L.	Elatine	Elatinaceae	Erect emergent	1967	1947
Eleocharis multicaulis (Smith) Desv.	Many-stalked spike rush	Cyperaceae	Erect emergent	1967	1967
Groenlandia densa (L.) Fourr.	Opposite-leaved pondweed	Potamogetonaceae	Submerged	1967	1947
Isoetes velata A. Braun	Quillwort	Isoetaceae	Amphibious submerged	1967	1952

Scientific name	Common name	Family	Growth Form	U.S. Introduction Date	Global Introduction Date
Luronium natans (L.) Raf.	Floating water-plantain	Alismataceae	Attached-floating; erect emergent; submerged	1897	1897
Myriophyllum oguraense Miki	Japanese myriophyllum	Haloragaceae	Sprawling emergent; submerged	1967	1967
Nymphaea rubra Roxb.	Indian red water-lily	Nymphaeaceae	Attached-floating	1897	1897
Potamogeton lucens L.	Shining pondweed	Potamogetonaceae	Submerged	1967	1952

* Naturalized outside of its native range both in the U.S. and globally for decades (Meisler 2009).

Table 5. *A priori* classifications and AqWRA risk levels for species based upon status in the U.S., Florida (FL), and the Great Lakes (GL) region. Dashed lines indicate that the species would likely not survive in the region based upon the regional hardiness zone climate screen. Those species were considered to have a low probability of invasion in the region and were not assessed.

Species name	U.S. *a priori* classification	U.S. Score	U.S. Risk	Florida *a priori* classification	FL Score	FL Risk	Great Lakes *a priori* classification	GL Score	GL Risk
Acorus calamus	Major invader	48	High	Non-invader	47	High	Minor invader	48	High
Acorus gramineus	Non-invader	20	Low	Non-invader	20	Low	Non-invader	20	Low
Aldrovanda vesiculosa	Non-invader	27	Low	Non-invader	26	Low	Non-invader	27	Low
Alisma plantago-aquatica	Minor invader	37	High	Non-invader	37	High	Minor invader	37	High
Alternanthera philoxeroides	Major invader	75	High	Major invader	74	High	Minor invader	75	High
Alternanthera sessilis	Major invader	44	High	Major invader	44	High	---	44	N/A
*Ammannia senegalensis**	Non-invader	14	Evaluate further	Non-invader	15	Evaluate further	---	14	N/A
Anubias afzelii	Non-invader	16	Low	Non-invader	17	Low	---	16	N/A
Anubias barteri	Non-invader	14	Low	Non-invader	15	Low	---	14	N/A
Anubias barteri var. *glabra*	Non-invader	14	Low	Non-invader	15	Low	---	14	N/A
Aponogeton crispus	Non-invader	14	Low	Non-invader	15	Low	---	14	N/A
Aponogeton distachyos	Minor invader	53	High	Non-invader	52	High	Non-invader	53	High
Aponogeton madagascariensis	Non-invader	19	Low	Non-invader	20	Low	---	19	N/A
Aponogeton natans	Non-invader	15	Low	Non-invader	16	Low	Non-invader	15	Low
Aponogeton ulvaceus	Non-invader	13	Low	Non-invader	14	Low	---	13	N/A
Barclaya longifolia	Non-invader	13	Low	Non-invader	14	Low	---	13	N/A
Bolbitis heteroclita	Non-invader	23	Low	Non-invader	23	Low	Non-invader	23	Low
Bolbitis heudelotii	Non-invader	17	Low	Non-invader	18	Low	---	17	N/A
Butomus umbellatus	Major invader	62	High	Non-invader	61	High	Major invader	62	High
Callitriche stagnalis	Major invader	38	High	Non-invader	42	High	Minor invader	42	High
Canna × generalis	Minor invader	23	Low	Minor invader	29	Low	Minor invader	26	Low
Canna indica	Minor invader	39	High	Minor invader	41	High	---	39	N/A
Cardamine lyrata	Non-invader	21	Low	Non-invader	21	Low	Non-invader	21	Low

Species name	U.S. *a priori* classification	U.S. Score	U.S. Risk	Florida *a priori* classification	FL Score	FL Risk	Great Lakes *a priori* classification	GL Score	GL Risk
Ceratophyllum muricatum subsp. *australe* (Florida*)	Minor invader	11	Low	Minor invader	17	Evaluate further	---	16	N/A
*Ceratophyllum submersum**	Non-invader	20	Evaluate further	Non-invader	19	Evaluate further	Non-invader	20	Evaluate further
Colocasia esculenta	Major invader	51	High	Major invader	52	High	---	51	N/A
Colysis pteropus (=*Microsorium pteropus*)	Non-invader	23	Low	Non-invader	23	Low	---	23	N/A
Crinum erubescens	Non-invader	20	Low	Non-invader	21	Low	---	20	N/A
Cryptocoryne × willisii	Non-invader	11	Low	Non-invader	14	Low	---	11	N/A
Cryptocoryne ciliata	Non-invader	19	Low	Non-invader	22	Low	---	19	N/A
Cryptocoryne cordata	Non-invader	14	Low	Non-invader	15	Low	---	14	N/A
Cryptocoryne crispatula	Non-invader	12	Low	Non-invader	15	Low	---	12	N/A
Cyperus difformis	Major invader	45	High	Minor invader	45	High	Minor invader	45	High
Cyperus involucratus	Major invader	35	High	Minor invader	35	High	Minor invader	35	High
Cyperus longus	Non-invader	19	Low	Non-invader	18	Low	Non-invader	19	Low
Cyperus prolifer	Minor invader	32	Low	Minor invader	35	High	---	36	Low
Cyperus serotinus	Minor invader	26	Low	Non-invader	27	Low	Minor invader	27	Low
Echinodorus martii (=*Echinodorus major*)	Non-invader	11	Low	Non-invader	12	Low	---	11	N/A
Echinodorus palaefolius	Non-invader	12	Low	Non-invader	13	Low	---	12	N/A
Echinodorus paniculatus	Non-invader	16	Low	Non-invader	17	Low	---	16	N/A
Echinodorus uruguayensis	Non-invader	12	Low	Non-invader	13	Low	---	12	N/A
Egeria densa	Major invader	71	High	Major invader	73	High	Major invader	71	High
Eichhornia azurea	Minor invader	33	High	Minor invader	34	High	---	34	N/A
Eichhornia crassipes	Major invader	81	High	Major invader	82	High	Minor invader	81	High
Eichhornia paniculata	Minor invader	25	Low	Minor invader	25	Low	---	25	N/A
Elatine macropoda	Non-invader	14	Low	Non-invader	14	Low	Non-invader	14	Low
Eriophorum latifolium	Non-invader	11	Low	Non-invader	11	Low	Non-invader	11	Low
Euryale ferox	Non-invader	19	Low	Non-invader	19	Low	Non-invader	19	Low
Glyceria fluitans	Minor invader	45	High	Non-invader	45	High	Minor invader	45	High

Species name	U.S. *a priori* classification	U.S. Score	U.S. Risk	Florida *a priori* classification	FL Score	FL Risk	Great Lakes *a priori* classification	GL Score	GL Risk
Glyceria maxima	Major invader	71	High	Non-invader	69	High	Major invader	71	High
Gratiola officinalis	Non-invader	28	Low	Non-invader	28	Low	Non-invader	28	Low
Gratiola peruviana	Non-invader	23	Low	Non-invader	23	Low	Non-invader	23	Low
Hesperantha coccinea	Non-invader	28	Low	Non-invader	27	Low	Non-invader	28	Low
Heteranthera zosterifolia	Non-invader	11	Low	Non-invader	12	Low	Non-invader	11	Low
Hottonia palustris	Non-invader	30	Low	Non-invader	29	Low	Non-invader	30	Low
Houttuynia cordata	Minor invader	37	High	Minor invader	40	High	Non-invader	40	High
Hydrilla verticillata	Major invader	79	High	Major invader	80	High	Major invader	79	High
Hydrocharis morsus-ranae	Major invader	62	High	Non-invader	61	High	Major invader	62	High
Hydrocleys nymphoides	Minor invader	46	High	Minor invader	46	High	--	46	N/A
Hydrocotyle vulgaris	Non-invader	33	High	Non-invader	31	Low	Non-invader	33	High
*Hygrophila corymbosa**	Minor invader	10	Evaluate further	Minor invader	11	Evaluate further	--	15	N/A
Hygrophila difformis	Minor invader	29	Low	Minor invader	30	Low	--	29	N/A
Hygrophila polysperma	Major invader	53	High	Major invader	61	High	--	59	N/A
Hymenachne amplexicaulis	Major invader	55	High	Major invader	58	High	--	55	N/A
Ipomoea aquatica	Major invader	62	High	Major invader	62	High	--	62	N/A
Iris ensata	Minor invader	25	Low	Non-invader	25	Low	Minor invader	25	Low
Iris pseudacorus	Major invader	58	High	Major invader	59	High	Major invader	58	High
Landoltia punctata	Major invader	38	High	Major invader	45	High	Minor invader	45	High
Lasia spinosa	Non-invader	20	Low	Non-invader	20	Low	Non-invader	20	Low
Lilaeopsis novae-zelandiae	Non-invader	19	Low	Non-invader	19	Low	Non-invader	19	Low
Limnocharis flava	Non-invader	55	High	Non-invader	56	High	--	55	N/A
Limnophila indica	Minor invader	17	Low	Minor invader	17	Low	--	22	N/A
Limnophila sessiliflora	Major invader	33	High	Major invader	42	High	Non-invader	44	High
Ludwigia adscendens	Non-invader	32	Low	Non-invader	32	Low	--	32	N/A
Ludwigia helminthorrhiza	Non-invader	16	Low	Non-invader	17	Low	Non-invader	16	Low
Ludwigia peruviana	Major invader	65	High	Major invader	65	High	--	65	N/A
Lythrum salicaria	Major invader	73	High	Non-invader	72	High	Major invader	73	High
Marsilea drummondii	Non-invader	22	Low	Non-invader	22	Low	Non-invader	22	Low

Species name	U.S. *a priori* classification	U.S. Score	U.S. Risk	Florida *a priori* classification	FL Score	FL Risk	Great Lakes *a priori* classification	GL Score	GL Risk
Marsilea quadrifolia	Major invader	61	High	Non-invader	60	High	Major invader	61	High
Mentha aquatica	Minor invader	37	High	Non-invader	36	High	Minor invader	37	High
Murdannia keisak	Major invader	24	Low	Minor invader	38	High	Non-invader	38	High
Myosotis scorpioides	Minor invader	38	High	Non-invader	37	High	Minor invader	38	High
Myriophyllum aquaticum	Major invader	75	High	Major invader	76	High	Minor invader	75	High
Myriophyllum spicatum	Major invader	81	High	Major invader	81	High	Major invader	81	High
Najas minor	Major invader	66	High	Minor invader	66	High	Major invader	66	High
Nasturtium microphyllum	Minor invader	35	High	Non-invader	33	High	Minor invader	35	High
Nasturtium officinale	Major invader	44	High	Minor invader	43	High	Major invader	44	High
Nechamandra alternifolia	Non-invader	20	Low	Non-invader	20	Low	Non-invader	20	Low
Nelumbo nucifera	Minor invader	38	High	Minor invader	39	High	Minor invader	38	High
Nymphaea × daubenyana	Minor invader	15	Low	Minor invader	18	Low	--	19	N/A
Nymphaea candida	Non-invader	17	Low	Non-invader	17	Low	Non-invader	17	Low
Nymphaea capensis var. *zanzibariensis*	Minor invader	25	Low	Minor invader	25	Low	--	26	N/A
Nymphaea colorata	Non-invader	16	Low	Non-invader	16	Low	--	16	N/A
Nymphaea lotus	Minor invader	39	High	Minor invader	39	High	Non-invader	39	High
Nymphoides crenata	Non-invader	17	Low	Non-invader	17	Low	Non-invader	17	Low
Nymphoides indica	Minor invader	29	Low	Minor invader	31	Low	Non-invader	30	Low
Nymphoides peltata	Major invader	74	High	Non-invader	73	High	Major invader	74	High
Oenanthe aquatica	Minor invader	35	High	Non-invader	35	High	Minor invader	35	High
Ottelia alismoides	Minor invader	37	High	Minor invader	37	High	Non-invader	37	High
Panicum repens	Major invader	63	High	Major invader	68	High	--	66	N/A
Persicaria hydropiper (=*Polygonum hydropiper*)	Minor invader	54	High	Minor invader	54	High	Minor invader	54	High
Philydrum lanuginosum	Non-invader	20	Low	Non-invader	20	Low	Non-invader	20	Low
Pistia stratiotes	Major invader	72	High	Major invader	73	High	Minor invader	72	High
Potamogeton crispus	Major invader	69	High	Minor invader	67	High	Major invader	69	High
Potamogeton gayii	Non-invader	12	Low	Non-invader	12	Low	Non-invader	12	Low
Potamogeton wrightii	Non-invader	19	Low	Non-invader	19	Low	Non-invader	19	Low

Species name	U.S. *a priori* classification	U.S. Score	U.S. Risk	Florida *a priori* classification	FL Score	FL Risk	Great Lakes *a priori* classification	GL Score	GL Risk
Ranunculus lingua	Non-invader	26	Low	Non-invader	25	Low	Non-invader	26	Low
Regnellidium diphyllum	Non-invader	19	Low	Non-invader	22	Low	--	19	N/A
Ricciocarpos natans	Minor invader	31	Low	Non-invader	36	High	Minor invader	37	High
Rotala rotundifolia	Major invader	33	High	Major invader	33	High	Non-invader	42	High
Sagittaria sagittifolia subsp. *leucopetala*	Non-invader	30	Low	Non-invader	29	Low	Non-invader	30	Low
Salvinia minima	Major invader	70	High	Major invader	70	High	--	70	N/A
Salvinia natans	Minor invader	57	High	Non-invader	57	High	Non-invader	57	High
Saururus chinensis	Non-invader	17	Low	Non-invader	17	Low	Non-invader	17	Low
Schoenoplectus glaucus (=*Bolboschoenus glaucus*)	Minor invader	21	Low	Non-invader	23	Low	Non-invader	23	Low
Schoenoplectus mucronatus	Major invader	40	High	Non-invader	40	High	Minor invader	40	High
Trapa natans	Major invader	66	High	Non-invader	66	High	Major invader	66	High
Typha × glauca	Major invader	51	High	--	50	N/A	Major invader	52	High
Typha angustifolia	Major invader	69	High	Non-invader	68	High	Major invader	69	High
Typha minima	Non-invader	27	Low	Non-invader	25	Low	Non-invader	27	Low
Urochloa mutica	Major invader	58	High	Major invader	59	High	--	58	N/A
Utricularia aurea	Non-invader	17	Low	Non-invader	17	Low	Non-invader	17	Low
Utricularia australis	Non-invader	22	Low	Non-invader	22	Low	Non-invader	22	Low
Utricularia stellaris	Non-invader	20	Low	Non-invader	20	Low	Non-invader	20	Low
Vallisneria spiralis	Major invader	69	High	Non-invader	68	High	Non-invader	69	High
Veronica beccabunga	Minor invader	32	Low	Non-invader	33	High	Minor invader	32	Low
Vesicularia dubyana	Non-invader	12	Low	Non-invader	13	Low	--	12	N/A
Victoria amazonica	Non-invader	18	Low	Non-invader	21	Low	--	18	N/A
Victoria cruziana	Non-invader	16	Low	Non-invader	19	Low	--	16	N/A
Wolffia welwitschii	Non-invader	15	Low	Non-invader	16	Low	Non-invader	15	Low

* Evaluate further outcomes were assigned to species with >5 unanswered questions.

Table 6. Diagnostics of model performance for the U.S. evaluation for all questions (Full) and without all combinations of the three sets of questions that were least frequently answered: 1.7, 2.1-3, and 4.1 and those that were often answered by default for both non-invaders and major invaders: 1.2-6, 5.1, 10.1 and 10.2. **Note:** only non-invaders and major invaders (n=97) were included for these analyses, resulting in a higher AUC for the full model than reported when all species were included in the analysis. Accuracy is the maximum percent of correct classification of invaders and non-invaders using the optimal threshold, the score above which the species are classified as invasive, and at and below which the species is classified as non-invasive. When multiple thresholds are listed, the accuracy is the same for all values of the threshold. AUC is the Area Under the Curve of the receiver operating characteristic curve (ROC).

Model	**No. of questions removed**	**Statistics**		
		Accuracy (%)	**Threshold**	**AUC**
Full	0	97	32	0.99
1.2	1	97	30	0.99
1.3	1	98	31	0.99
1.4	1	97	31	0.99
1.5	1	97	32	0.99
1.6	1	97	31	0.99
1.7	1	97	28	0.99
2.1	1	97	31	0.99
2.2	1	97	30	0.99
2.3	1	96	29, 30, 31, 32	0.99
4.1	1	97	32	0.99
5.1	1	96	29, 30, 31, 32, 33	0.99
10.1	1	97	32	0.99
10.2	1	97	31	0.99
1.2-7, 2.1-3, 4.1, 5.1, 10.1-2	13	97	19	0.99

Table 7. Results for 20 validation species results. The threshold of 32 developed for the AqWRA model results in 100% accuracy in risk prediction for both major and non-invaders.

Species	Common name	*a priori* category	Score	Risk
Azolla pinnata subsp. *asiatica*	Mosquito fern	Invader	65	High
Glossostigma cleistanthum	Mudmat	Invader	52*	High
Glyceria declinata	Mannagrass	Invader	59*	High
Ludwigia grandiflora subsp. *hexapetala*	Water-primrose	Invader	74	High
Luziola subintegra	Tropical American watergrass	Invader	37*	High
Marsilea minuta	Hairy pepperwort	Invader	50	High
Marsilea mutica	Australian water-clover	Invader	42	High
Nymphoides cristata	Crested floatingheart	Invader	43*	High
Rorippa amphibia	Great yellow-cress	Invader	35	High
Salvinia molesta	Giant salvinia	Invader	72	High
Blyxa japonica	Blyxa	Non-invader	24	Low
Cabomba aquatica	Yellow cabomba	Non-invader	31	Low
Elatine alsinastrum	Elatine	Non-invader	18	Low
Eleocharis multicaulis	Many-stalked spike rush	Non-invader	21	Low
Groenlandia densa	Opposite-leaved pondweed	Non-invader	17	Low
Isoëtes velata	Quillwort	Non-invader	18	Low
Luronium natans	Floating water-plantain	Non-invader	28	Low
Myriophyllum oguraense	Japanese myriophyllum	Non-invader	16	Low
Nymphaea rubra	Indian red water-lily	Non-invader	15	Low
Potamogeton lucens	Shining pondweed	Non-invader	17	Low

*Some impact data from U.S. populations were used for assessment.

Table 8. All species assessed sorted by U.S. score (n=150, including test and validation species). Shaded species should be considered as potentially high priority for management based on their scores and other criteria (see text).

Species	***U.S. a priori* classification**	**Score[1]**	**Risk**
Cryptocoryne × willisii	Non-invader	11	Low
Echinodorus martii (=*Echinodorus major*)	Non-invader	11	Low
Eriophorum latifolium	Non-invader	11	Low
Heteranthera zosterifolia	Non-invader	11	Low
Cryptocoryne crispatula	Non-invader	12	Low
Echinodorus palaefolius	Non-invader	12	Low
Echinodorus uruguayensis	Non-invader	12	Low
Potamogeton gayii	Non-invader	12	Low
Vesicularia dubyana	Non-invader	12	Low
Aponogeton ulvaceus	Non-invader	13	Low
Barclaya longifolia	Non-invader	13	Low
Ammannia senegalensis	Non-invader	14	Evaluate further
Anubias barteri	Non-invader	14	Low
Anubias barteri var. *glabra*	Non-invader	14	Low
Aponogeton crispus	Non-invader	14	Low
Cryptocoryne cordata	Non-invader	14	Low
Elatine macropoda	Non-invader	14	Low
Aponogeton natans	Non-invader	15	Low
Hygrophila corymbosa	Minor invader	15*	Evaluate further
Nymphaea rubra	Non-invader	15	Low
Wolffia welwitschii	Non-invader	15	Low
Anubias afzelii	Non-invader	16	Low
Echinodorus paniculatus	Non-invader	16	Low
Ludwigia helminthorrhiza	Non-invader	16	Low
Myriophyllum oguraense	Non-invader	16	Low
Nymphaea colorata	Non-invader	16	Low
Victoria cruziana	Non-invader	16	Low
Bolbitis heudelotii	Non-invader	17	Low
Ceratophyllum muricatum subsp. *australe*	Minor invader	17*	Low
Groenlandia densa	Non-invader	17	Low
Nymphaea candida	Non-invader	17	Low
Nymphoides crenata	Non-invader	17	Low
Potamogeton lucens	Non-invader	17	Low
Saururus chinensis	Non-invader	17	Low
Utricularia aurea	Non-invader	17	Low
Elatine alsinastrum	Non-invader	18	Low
Isoëtes velata	Non-invader	18	Low
Victoria amazonica	Non-invader	18	Low
Aponogeton madagascariensis	Non-invader	19	Low
Cryptocoryne ciliata	Non-invader	19	Low

Species	***U.S. a priori* classification**	**Score[1]**	**Risk**
Cyperus longus	Non-invader	19	Low
Euryale ferox	Non-invader	19	Low
Lilaeopsis novae-zelandiae	Non-invader	19	Low
Nymphaea × daubenyana	Minor invader	19*	Low
Potamogeton wrightii	Non-invader	19	Low
Regnellidium diphyllum	Non-invader	19	Low
Acorus gramineus	Non-invader	20	Low
Ceratophyllum submersum	Non-invader	20	Evaluate further
Crinum erubescens	Non-invader	20	Low
Lasia spinosa	Non-invader	20	Low
Nechamandra alternifolia	Non-invader	20	Low
Philydrum lanuginosum	Non-invader	20	Low
Utricularia stellaris	Non-invader	20	Low
Cardamine lyrata	Non-invader	21	Low
Eleocharis multicaulis	Non-invader	21	Low
Schoenoplectus glaucus (=*Bolboschoenus glaucus*)	Minor invader	21	Low
Limnophila indica	Minor invader	22*	Low
Marsilea drummondii	Non-invader	22	Low
Utricularia australis	Non-invader	22	Low
Bolbitis heteroclita	Non-invader	23	Low
Colysis pteropus (=*Microsorium pteropus*)	Non-invader	23	Low
Gratiola peruviana	Non-invader	23	Low
Blyxa japonica	Non-invader	24	Low
Eichhornia paniculata	Minor invader	25	Low
Iris ensata	Minor invader	25	Low
Nymphaea capensis var. *zanzibariensis*	Minor invader	25	Low
Cyperus serotinus	Minor invader	26	Low
Ranunculus lingua	Non-invader	26	Low
Aldrovanda vesiculosa	Non-invader	27	Low
Typha minima	Non-invader	27	Low
Gratiola officinalis	Non-invader	28	Low
Hesperantha coccinea	Non-invader	28	Low
Luronium natans	Non-invader	28	Low
Canna × generalis	Minor invader	29*	Low
Hygrophila difformis	Minor invader	29	Low
Nymphoides indica	Minor invader	29	Low
Hottonia palustris	Non-invader	30	Low
Sagittaria sagittifolia subsp. *leucopetala*[5]	Non-invader	30	Low
Cabomba aquatica	Non-invader	31	Low
Ludwigia adscendens	Non-invader	32	Low
Veronica beccabunga	Minor invader	32	Low
Eichhornia azurea[5]	Minor invader	33	High
Hydrocotyle vulgaris	Non-invader	33[2]	High
Cyperus involucratus	Major invader	35	High

Species	*U.S. a priori* classification	Score[1]	Risk
Nasturtium microphyllum	Minor invader	35	High
Oenanthe aquatica	Minor invader	35	High
Rorippa amphibia	Major invader	35[4]	High
Cyperus prolifer	Minor invader	36*	High
Alisma plantago-aquatica	Minor invader	37	High
Houttuynia cordata	Minor invader	37	High
Luziola subintegra	Major invader	37*[2]	High
Mentha aquatica	Minor invader	37	High
Ottelia alismoides[5]	Minor invader	37	High
Ricciocarpos natans	Minor invader	37*	High
Murdannia keisak	Major invader	38*	High
Myosotis scorpioides	Minor invader	38	High
Nelumbo nucifera	Minor invader	38	High
Canna indica	Minor invader	39	High
Nymphaea lotus	Minor invader	39	High
Schoenoplectus mucronatus	Major invader	40	High
Callitriche stagnalis	Major invader	42*	High
Marsilea mutica	Major invader	42[2]	High
Rotala rotundifolia	Major invader	42*	High
Nymphoides cristata	Major invader	43*[2]	High
Alternanthera sessilis[5]	Major invader	44	High
Limnophila sessiliflora[5]	Major invader	44*	High
Nasturtium officinale	Major invader	44	High
Cyperus difformis	Major invader	45	High
Glyceria fluitans	Minor invader	45	High
Landoltia punctata	Major invader	45*	High
Hydrocleys nymphoides	Minor invader	46[3]	High
Acorus calamus	Major invader	48	High
Marsilea minuta	Major invader	50[2]	High
Colocasia esculenta	Major invader	51	High
Typha × glauca	Major invader	51	High
Glossostigma cleistanthum	Major invader	52*[2]	High
Aponogeton distachyos	Minor invader	53[4]	High
Persicaria hydropiper (=*Polygonum hydropiper*)	Minor invader	54	High
Hymenachne amplexicaulis	Major invader	55	High
Limnocharis flava	Non-invader	55	High
Salvinia natans	Minor invader	57	High
Iris pseudacorus	Major invader	58	High
Urochloa mutica	Major invader	58	High
Glyceria declinata	Major invader	59*	High
Hygrophila polysperma[5]	Major invader	61*	High
Marsilea quadrifolia	Major invader	61	High
Butomus umbellatus	Major invader	62	High
Hydrocharis morsus-ranae	Major invader	62[4]	High

Species	*U.S. a priori* classification	Score[1]	Risk
Ipomoea aquatica[5]	Major invader	62	High
Azolla pinnata subsp. *asiatica*[5]	Major Invader	65[2]	High
Ludwigia peruviana	Major invader	65	High
Najas minor	Major invader	66	High
Trapa natans	Major invader	66	High
Panicum repens	Major invader	68*	High
Potamogeton crispus	Major invader	69	High
Typha angustifolia	Major invader	69	High
Vallisneria spiralis	Major invader	69	High
Salvinia minima	Major invader	70	High
Egeria densa	Major invader	71	High
Glyceria maxima	Major invader	71	High
Pistia stratiotes	Major invader	72	High
Salvinia molesta[5]	Major Invader	72[2]	High
Lythrum salicaria	Major invader	73	High
Ludwigia grandiflora subsp. *hexapetala*	Major Invader	74	High
Nymphoides peltata	Major invader	74	High
Alternanthera philoxeroides	Major invader	75	High
Myriophyllum aquaticum	Major invader	75	High
Hydrilla verticillata[5]	Major invader	79	High
Eichhornia crassipes	Major invader	81	High
Myriophyllum spicatum	Major invader	81	High

*Some impact data from U.S. populations were used for assessment. Scores reported are the highest found in any of the three regional assessments if the U.S. score deviated from a higher score by more than 3 points (the climate question might cause variance of up to 3 points).

[1] All species with scores above 60 highlighted as management priorities.

[2] Species with scores above 32 that have been in the U.S. for <30 years.

[3] Species that are currently minor invaders in the U.S. but are highly invasive in other countries.

[4] Species that are currently present in a small subset of the U.S. Department of Agriculture Hardiness Zones they have been documented to tolerate.

[5] Species listed as Noxious Weeds by the US. Department of Agriculture (http://www.aphis.usda.gov/plant_health/plant_pest_info_weeds/ downloads/weedlist-2010doc.pdf). Full species of the two sub-species included are listed as Noxious Weeds.

Figure 1. AqWRA score for U.S. test by *a priori* invasiveness category.

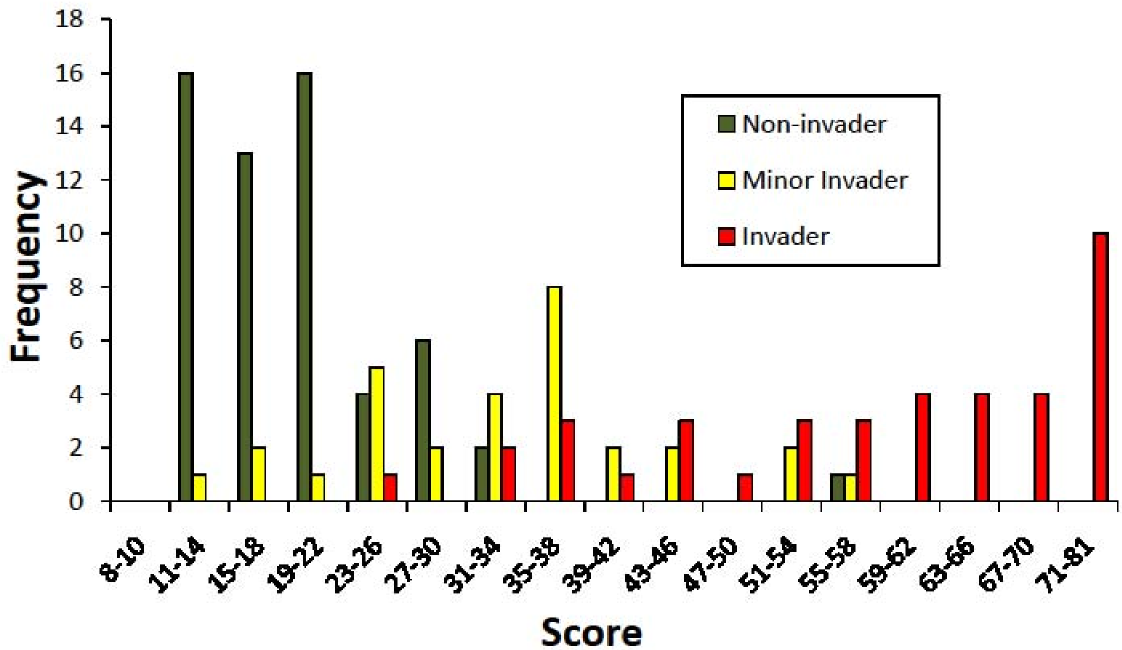


Figure 2. AqWRA score for U.S. test by aquatic plant growth form.

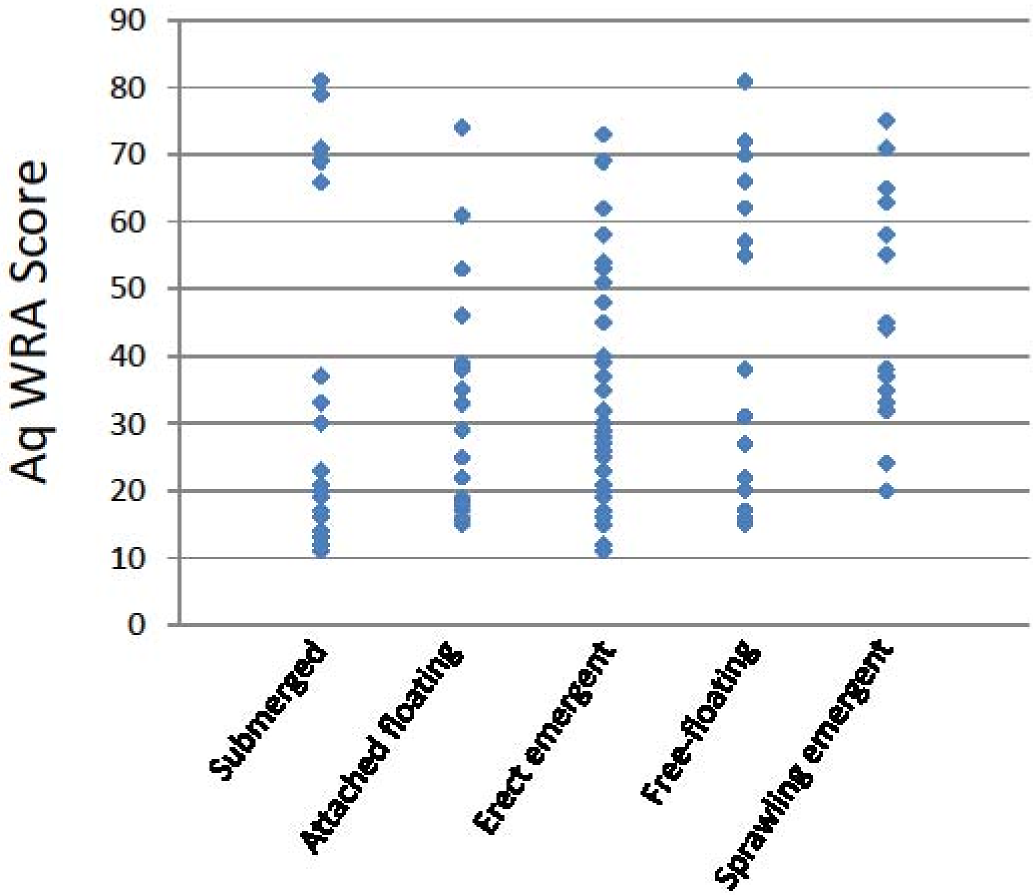
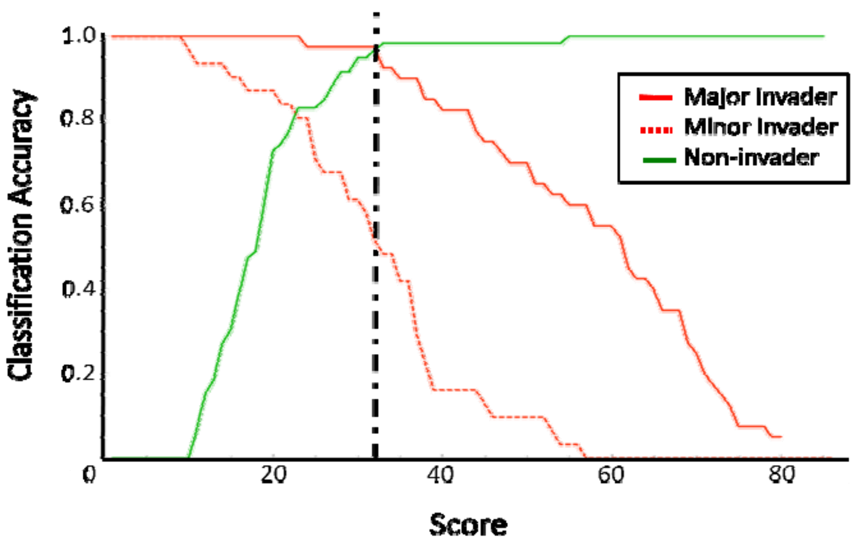


Figure 3. Accuracy of the AqWRA model for the U.S. for non-invaders and major invaders in Table 1. The maximum accuracy of 97% with a score threshold of 32 suggests that species with scores of 33 and above are major invaders, while species with scores of 32 and below are non-invaders: A. Score data for all species; B. Cumulative percent accuracy. Minor invaders and species requiring further evaluation were excluded from the accuracy assessment as their eventual invasion status is unknown (n=97: 58 non-invaders and 39 major invaders).

A.



B.

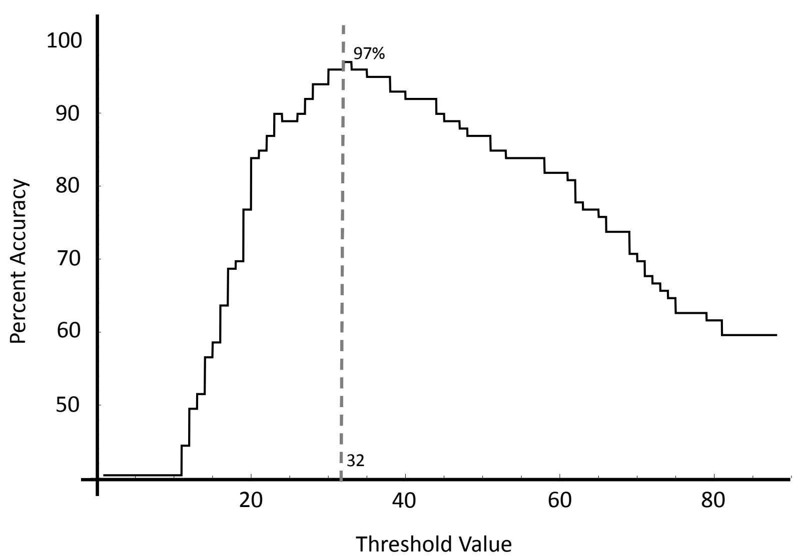


Figure 4. Receiver Operator Curve for the AqWRA using U.S. data for all species (n=127) with minor and major invaders combined as invaders compared to non-invaders. The closer the Area Under the Curve (AUC) to 1.0, the more completely the model distinguishes the two groups.

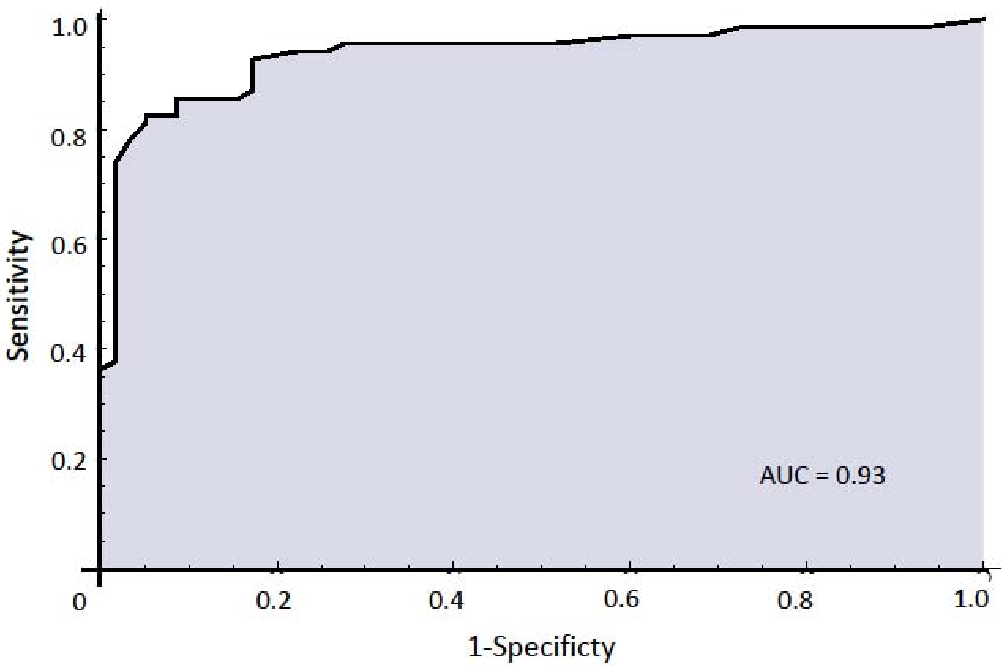
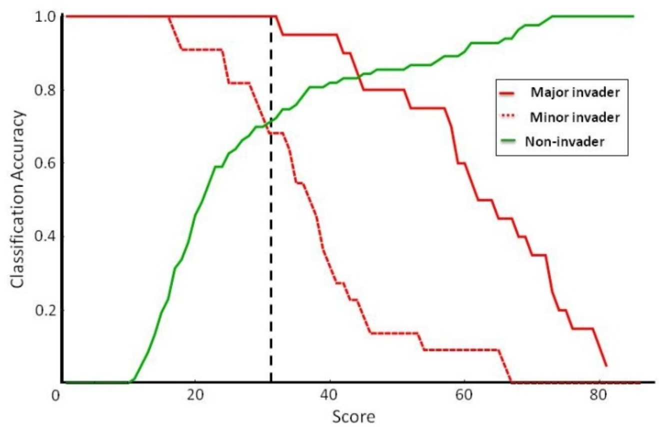
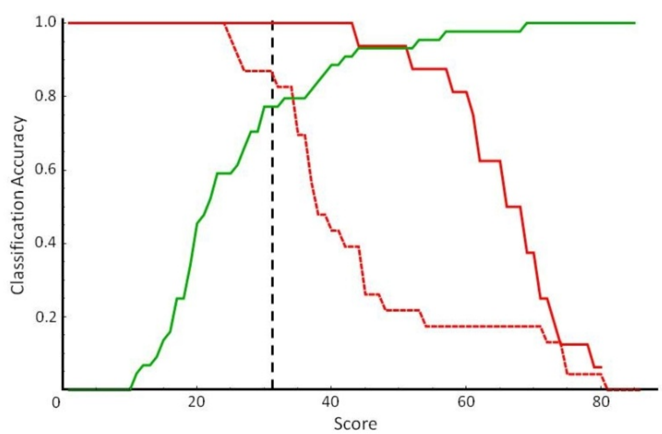


Figure 5. Accuracy of the AqWRA model for the: A. Florida (n=103) and B. Great Lakes (n=60) regional tests. Data are for species in Table 5. The U.S. threshold scores of 33 and above considered invaders, while species with scores of 32 and below are non-invaders. Overall accuracy in distinguishing non-invaders from major invaders for Florida with this threshold is 77%, and for the Great Lakes is 83%.

A. Florida



B. Great Lakes



Appendix A. Comparison of questions and scoring between the New Zealand Aquatic Weed Risk Assessment (Champion and Clayton 2000) and the AqWRA for the U.S. used for the analyses described in this report.

Question - NZ	Question - AqWRA	Score and guidance - NZ	Score and guidance – AqWRA for U.S.
Temperature tolerance (1.1)	Temperature tolerance (1.1)	**(0-3)** Maximum if frost tolerant, 2 if growth checked by winter temps, 1 if dies off over winter, 0 if killed over winter.	**(0-3)** Score 3 if maintains photosynthetic tissue and summer growth form throughout winter, 2 if dies back to tuber/bulb/rhizome (or similar structure) during winter, 1 if adult plants completely die but viable seeds remain. Also refer to regional scoring guidelines in the Weed Risk Assessment tool (Table 1). We default to 1 for annual species.
Range of habitat (1.2)	Range of habitat (1.2)	**(1-3)** Maximum if able to grow from water to dry land, 2 if water to wetland, or from shallow to deep (>5 m) water, 1 narrow range.	**(1-3)** Score 3 if able to grow from water to dry land, 2 if water to wetland, or from shallow to deep (>5 m) water, 1 narrow range. Default = 1 if no information is available; 2 for free-floating plants, unless more information is available.
Water/substrate type (1.3)	Water/substrate type tolerance (1.3)	**(1-2)** Maximum if tolerant of sandy to muddy (or peaty) substrate, or oligotrophic to eutrophic waters, 1 if restricted by either.	**(1-2)** Score 2 if tolerant of sandy to muddy (or peaty) substrate, or oligotrophic to eutrophic waters, 1 if restricted by either. Default = 1 if no information is available.
Water clarity (1.4)	Water clarity tolerance (1.4)	**(0-1)** Maximum if unaffected by water clarity, i.e. floating, or emergent.	**(0-1)** Score 1 if unaffected by water clarity (i.e. floating or emergent, or submergents tolerant of very low light levels, such as *Myriophyllum spicatum* and *Hydrilla verticillata*), 0 if affected by water clarity.
Salinity (1.5)	Salinity tolerance (1.5)	**(0-1)** Can tolerate saline conditions, or not.	**(0-1)** Score 1 if species can tolerate saline conditions, 0 if not. Habitat information can be used to determine a score of 0 if species is only found to occur in freshwater habitats.
N/A	pH tolerance (1.6)	Question not included in assessment.	**(0-1)** Score 1 if tolerant of both acidic and basic pH or no information is available, 0 if restricted to neutral, basic, or acidic pH.

Water level fluctuation - (1.7)	Water level fluctuation - Tolerates periodic flooding/drying (1.7)	*Question was not included in the original assessment, but was included in assessments developed for Australia and Micronesia.* **(0-3)** Maximum if able to tolerate one month dewatering.	**(0-3)** Score 3 for species which have evidence of tolerating periodic flooding/drying with a specified time period longer than 1 month (e.g., "months"; "X months", "winter flooding"), 2 for evidence of tolerance of flooding/drying over a period of days/a couple of weeks, 1 for species that die back during periods of flooding/drying, and 0 for species that do not tolerate flooding/drying. Do not score if there is no information available.
Lentic - rivers, streams, drains, irrigation channels (2.1)	Lentic - rivers, streams, drains, or other flowing waters, including their margins (2.1)	**(0-3)** Maximum if major weed, 2 if minor weed, 1 if present but not weedy, 0 absent.	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.
Lotic - ponds, shallow and deep lakes (2.2)	Ponds, lakes and other standing waters, including their margins (2.2)	**(0-3)** Maximum if major weed, 2 if minor weed, 1 if present but not weedy, 0 absent.	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.
Wetland - water margin, swamp, marsh, bog (2.3)	Swamp, marsh, bog, or other wet areas not covered by 2.1 or 2.2 (2.3)	**(0-3)** Maximum if major weed, 2 if minor weed, 1 if present but not weedy, 0 absent.	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed, 1 if present but not weedy, 0 if absent.
Establishment – Existing vegetation (2.4)	Establishment – into existing vegetation (2.4)	*Question was not included in the original assessment, but was included in the assessment developed for Micronesia.* **(-5 - 0)** Maximum if able to invade unmodified vegetation.	**(-5 - 0)** Score 0 if able to invade unmodified vegetation, -3 if the species can only colonize certain types of vegetation (e.g., turf-forming shoreline vegetation), -5 if there is no evidence that the species can move into intact vegetation. Default = 0 if there is evidence of establishment, but no specific information about level of invasion into existing vegetation and/or type of vegetation being invaded. Default = -3 for species that have not naturalized outside of their native range.

Establishment - Disturbance (2.5)	Establishment – into disturbed vegetation (2.5)	*Question was not included in the original assessment, but was included in the assessment developed for Micronesia.* **(0 - 5)** Maximum if able to aggressively colonise following vegetation clearance, newly constructed waterbodies or nutrient enrichment.	**(0 - 5)** Score 5 if able to aggressively colonize following vegetation clearance, newly constructed waterbodies or nutrient enrichment, 1 if the species grows in disturbed areas, but there is no other information, 0 if there is no evidence of establishment in disturbed areas. Information from either the native or introduced range may be used to answer this question. Default = 1 for no information.
Competitive ability - Within growth form, i.e. submerged, floating, emergent (3.1)	N/A*	**(0-8)** e.g. Maximum *Hydrilla:Ceratophyllum:Egeria/ Lagarosiphon/Elodea/P. crispus*/native species.	N/A
Competitive ability - Between growth form (3.2)	Competition – between growth form (3.1)	**(0, 1, 2)** Maximum if able to completely displace another growth form, 1 if some suppression, 0 no interaction.	**(0, 1, 2)** Score 2 if species forms dense stands that are documented to displace other growth forms (submerged, floating, emergent), 1 if some suppression, 0 if no displacement. Default = 0 if species has been in the trade globally for >30 years and there is no information about the species displacing other growth forms.
Dispersal outside catchment by natural agents, e.g. birds, wind (4.1)	Dispersal outside catchment by natural agents (e.g. birds, wind) (4.1)	**(0, 1, 3, 5)** Maximum if propagule well adapted for bird/wind distribution, 1 if propagule could be spread in bird crop.	**(0, 1, 3, 5)** Score 5 if species (including seeds, rhizomes, fragments etc.) well adapted, and likely to be frequently dispersed, by natural agents, 3 if transport by natural agents is possible but uncommon, 1 if propagule could be spread in bird crop, 0 if no, or extremely low, likelihood of dispersal by natural agents (e.g., Hydrilla is scored 1 because its turions can survive passage through duck guts, an agent of dispersal, but this is believed to happen rarely).
Dispersal outside catchment by accidental human activity, e.g.	Dispersal outside catchment by accidental human activity (4.2)	**(0-3)** Maximum if spread by 3 methods, etc.	**(1, 2, 3)** Score 3 if major pathway, seeds/fragments adapted for easy transportation (e.g., via boat/trailer, fishing gear), 2 if the species is a floating plant or a macrophyte, but no explicit mention of high spread in the

drainage machinery, boat trailers, eel nets (4.2)			literature, 1 not mentioned, not likely to be spread by human activity based on growth form and life history. Default = 1 if no information is available.
Dispersal outside catchment by deliberate introduction (4.3)	Dispersal outside catchment by deliberate introduction (4.3)	**(0-1)** Maximum if attractive to humans (ornamental fishpond or aquarium). If species is not used or no information exists, it should be scored a 0.	**(0-1)** Score 1 if species is desirable to humans (e.g., or used for medicinal, food, ornamental, restoration, etc. purposes in the U.S. or elsewhere). If species is not used or no information exists, it should be scored a 0.
Effective spread within waterbody/ catchment (4.4)	Effective spread within waterbody/ catchment (4.4)	**(0-1)** Maximum if effective spread within waterbody by seed, or plant fragments.	**(0-1)** Score 1 for extensive spread within a waterbody or among waterbodies, 0 for no spread. Occurrence along streams or riverbanks or in rivers can be used as evidence, as well as evidence of water dispersal. Do not answer if there is no information available.
Maturation rate. (5.1)	Generation time (time between germination of an individual and the production of living offspring, not seeds or other dormant structures) (5.1)	**(1-3)** Includes growth rate and time to maturity under ideal conditions.	**(1, 2, 3)** Score 3 if rapid (reproduction in first year and >1 generation/year), 2 if annual or produces one generation every year including the first year, 1 if not reproductively mature in the first year. Default = 1 if no information is available.
Seeding ability - Quantity (6.1)	Seeding ability - Quantity (5.1)	**(0-3)** Maximum if >1000 seeds/plant, 2 100-1000, 1 <100, 0 nil.	**(0-3)** Score 3 if >1000 seeds/plant/year, 2 100-1000, 1 <100 and/or evidence that seed are produced (in native or introduced range), 0 if seed not produced.
Seeding ability – Viability/ persistence (6.2)	Seeding ability - Viability/ persistence (6.2)	**(0-2)** Maximum if high viability for several years, 1 low viability.	**(0-2)** Score 2 if highly viable for >3 years, 1 low viability or evidence of seed production with no information on viability, 0 no viable seeds.
Cloning ability (7.1)	Vegetative reproduction (7.1)	**(0-5)** Maximum for far-reaching rhizomes/stolons/fragmentation capable of forming new colonies, 3 for rhizome/stolons, 1 for clump forming, 0 no vegetative spread.	**(0, 1, 3, 5)** Score 5 for naturally fragmenting from rhizomes, stolons, or other vegetative growth into tissue capable of producing new colonies (e.g., *Egeria densa*), 3 if produces rhizomes/stolons, but there is no other information about the formation of new colonies elsewhere, 1 for clump-forming by vegetative spread, 0

			for no vegetative spread.
Obstruction – Physical – water use (recreation) (8.1)	Physical-water use, recreation (8.1)	**(0-2)** Maximum for major nuisance, 1 minor nuisance.	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default to 0.
Obstruction – Physical – access (8.2)	Physical – access (8.2)	**(0-2)** Maximum for major nuisance, 1 minor nuisance.	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default to 0.
Obstruction – Physical – water flow, power generation (8.3)	Physical - water flow, power generation (8.3)	**(0-2)** Maximum for major nuisance, 1 minor nuisance.	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default to 0.
Obstruction – Physical – irrigation, flood control (8.4)	Physical - irrigation, flood control (8.4)	**(0-2)** Maximum for major nuisance, 1 minor nuisance.	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default to 0.
Aesthetic – visual, olfactory (8.5)	Aesthetic - visual, olfactory (8.5)	**(0-2)** Maximum for both visual and smell problems, 1 either.	**(0-2)** Score 2 for both visual and odor problems, 1 either, 0 neither or no mention of these impacts. Surface matting of macrophytes scores 1 for visual impact.
Damage to natural areas - Reduce biodiversity (9.1)	Reduces biodiversity (9.1)	**(0, 1, 3, 5)** Maximum for forming monospecific stands, reducing score for lessening impact.	**(0, 1, 3, 5)** Score 5 for extensive monospecific stands, 3 for species that become dominant, 1 for small monospecific stands, and 0 if species does not become dominant over other species. We default to 0 for this question if species has been in the trade globally for >30 years and there is no information found or if the species is not naturalized outside of its native range.
Damage to natural areas - Reduce water quality (9.2)	Reduces water quality (9.2)	**(0-3)** Maximum for major impacts especially deoxygenation.	**(0, 1, 3)** Score 3 if evidence that this species causes deoxygenation (e.g., through extensive growth in shallow water) or other water quality loss (e.g., loss of water

			clarity because of high decomposition rates continuously during the growing season), 1 if deoxygenation or other water quality loss is likely based on seasonal growth cycles (e.g., macrophyte that gets to high density and dies off at end of summer), 0 otherwise. We default to 0 for this question if species has been in the trade globally for >30 years and there is no information found or if the species is not naturalized outside of its native range.
Damage to natural areas - Negatively affect physical processes (9.3)	Negatively affect physical processes (9.3)	**(0-2)** Maximum for major effects on substrate stability, hydrology (flooding).	**(0, 2)** Score 2 if species alters hydrology (e.g., increases the chance of flooding) or substrate stability (e.g., increases amount of sediment erosion or deposition), or other physical processes, 0 if the species has no history of modifying physical processes. Default = 0 for this question if species has been in the trade globally for >30 years and there is no information found or if the species is not naturalized outside of its native range.
Other undesirable traits - Health impairment, e.g. drowning, poisonous, sharp leaf edges, mosquito breeding habitat (10.1)	Human health impairment (e.g. drowning, poisonous, mosquito habitat) (10.1)	**(0-2)** Maximum for 2 or more effects.	**(0-2)** Score 1 for one effect, 2 for 2 or more effects.
Other undesirable traits - Weed of agriculture (10.2)	Weed of agriculture, including crops, livestock and aquaculture (10.2)	**(0-1)** Maximum if a problem land weed.	**(0-1)** Score 1 if a problem agricultural weed, 0 if no evidence that it is an agricultural weed, or if evidence states that species is in agricultural areas but not problematic.
Extent of suitable habitat (11.1)	N/A*	Available habitat present in NZ scored out of 10, amount of available habitat not occupied scored as a fraction, e.g. alligator weed 4/6 (scores 4), raupo 0/10 (scores 0), hydrilla 9/10 (scores 9).	N/A

Resistance to management - Ease of implementation (12.1)	Management - Ease of management implementation (11.1)	**(0-2)** Maximum if accessibility to weed is difficult, e.g. dense tall impenetrable growths.	**(0-2)** Score 2 if accessibility to weed is difficult, e.g. dense tall impenetrable growths or growing in habitats that are difficult to access by roads or waterways (e.g., swamps). For species that have naturalized outside of their native range, default = 0-2 based upon evidence about habitat and/or growth form if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Resistance to management - Recognition of problem (12.2)	Management - Recognition of management problem (11.2)	**(0-1)** Maximum if difficult to assess weed, e.g. submerged.	**(0-1)** Score 1 if difficult to assess weed, e.g. submerged; looks like another species. For species that have naturalized outside of their native range, default to a score between 0-1 based upon growth form evidence if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Resistance to management - Scope of control methods (12.3)	Management - Scope of control methods (11.3)	**(0-2)** Maximum if no control method, 1 if only one control option.	**(0-2)** Score 2 if no control method, 1 if only one control option. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Resistance to management - Suitability (12.4)	Management - Control method suitability (11.4)	**(0-1)** Maximum if control method not always acceptable, e.g. grass carp, unregistered herbicide.	**(0-1)** Score 1 if control method not always acceptable, e.g. grass carp, unregistered herbicide. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Resistance to	Management -	**(0-2)** Maximum if ineffective, 1 if partial	**(0-2)** Score 2 if ineffective, 1 if partial control. If species

management - Effectiveness (12.5)	Effectiveness of control (11.5)	control.	has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Resistance to management - Duration of control (12.6)	Management - Duration of control (11.6)	**(0-2)** Maximum if no control, 1 if control for 3+ months.	**(0-2)** Score 2 if no control, 1 if control for 3+ months. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.
Problem in other countries (13.1)	Problem in other countries (12.1)	**(0 - 5)** Maximum if widespread problem weed in other temperate countries, 4 only problem in some temperate countries, 3 if adventive, not weedy in other temperate countries, 2 if tropical weed, 1 if adventive, but not weedy in tropics, 0 not adventive elsewhere.	**(0, 1, 3, 4, 5)** Score 5 if species has been reported to be a widespread problem (i.e., a harmful weed in many other countries), 4 if species has been reported to be a harmful weed in 5 or fewer countries, 3 if species has been reported to be a widespread adventive (but not a harmful weed) in many other countries, 1 if species has been reported to be adventive in 5 or fewer countries, 0 if not adventive elsewhere.

* Removed from assessment (see text).

Appendix B. AqWRA scores and risk levels for non-native aquatic species listed as Invasive Species on US Army Corps of Engineers Projects (data provided by Jessica Spencer, 2010).

Common name	**Scientific name**	**Score**	**Risk**
Alligator weed	*Alternanthera philoxeroides*	75	High
Aquatic forget-me-not	*Myosotis scorpioides*	38	High
Brazilian waterweed	*Egeria densa*	71	High
Brittle waternymph	*Najas minor*	66	High
Cattail	*Typha angustifolia*	69	High
Curly-leaf pondweed	*Potamogeton crispus*	69	High
Dotted duckweed	*Landoltia punctata*	38	High
Eurasian water-milfoil	*Myriophyllum spicatum*	81	High
Flowering rush	*Butomus umbellatus*	62	High
Giant salvinia	*Salvinia molesta*	72	High
Hydrilla	*Hydrilla verticillata*	79	High
Parrots feather	*Myriophyllum aquaticum*	75	High
Purple loosestrife	*Lythrum salicaria*	73	High
Torpedo grass	*Panicum repens*	63	High
Water hyacinth	*Eichhornia crassipes*	81	High
Water lettuce	*Pistia stratiotes*	72	High
Water primrose	*Ludwigia grandiflora* subsp. *hexapetala*	66	High
Water spinach	*Ipomoea aquatica*	62	High
West Indian marsh grass	*Hymenachne amplexicaulis*	55	High
Wild taro	*Colocasia esculenta*	51	High
Yellow water flag	*Iris pseudacorus*	58	High