Risk analysis for invasive plants in Iowa: Development of risk-assessment models and the perceptions of stakeholders

by

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ABSTRACT

Risk analysis is a decision-making framework used to evaluate risk, or the probability of harm given an exposure. Invasive plants pose risks to natural ecosystems because they can significantly alter ecosystem function and decrease native species diversity. Managing these risks comes with many challenges, and may take many forms. This thesis examines two primary aspects of risk analysis: (1) the validation and development of risk-assessment models that can predict the naturalization of non-native woody plants; and (2) the perspectives of stakeholders on invasive plants, risk-assessment models, and nature relatedness.

Good power and accuracy are primary goals of risk-assessment models to predict the naturalization of non-native plants. Testing previously developed models with a new set of species, or external validation, is one way to ensure these goals are met. Validation of four risk-assessment models - previously designed to evaluate the risk of naturalization for woody plants in Iowa - had mixed results when applied to a new selection of species. Classification rates ranged from 62.1 to 93.1%, biologically significant error rates from 11.5 to 18.5%, and horticulturally limiting error rates from 11.1 to 38.5%. Another way to reach the goal of good power and accuracy is to develop new risk-assessment models based on different statistical techniques. Creation of a new risk-assessment model for Iowa using a random forest approach yielded a high initial classification rate (92.0%), no biologically significant errors and 8.7% horticulturally limiting errors. When validated, the random forest model maintained a relatively high classification rate (82.8%), but produced one biologically significant error (4.2%) and more horticulturally limiting errors (29.2%). Differences in performance among the various models were not always significant due to the small sample size of the validating data set (n = 29), but the random forest model shows promise as a new technique to sort benign non-native woody plants from naturalizing or invasive ones.

Implementation of risk-assessment models will depend on the cooperation of diverse stakeholder groups. Addressing their perspectives on invasive plants is therefore an important component of the risk analysis process. Stakeholders in Iowa who will be affected by or involved in implementation of risk-assessment models agreed that invasive plants are a problem that we have a responsibility to manage. Respondents had a strong sense of their personal relatedness to nature, which played some role in shaping their concern about invasive plants. Support for use of risk-assessment models was high, though respondents expressed some concerns about accuracy. Respondents were willing to accept biologically significant error rates of 5 to 10%, and horticulturally limiting error rates of 10 to 20%; overall they found biologically significant errors to be more important than horticulturally limiting errors. Because stakeholders are largely in agreement about invasive plants and their management, risk management efforts in Iowa that incorporate risk-assessment models are more likely to be successful than if stakeholder groups disagreed. Mixed results of efforts to validate existing risk-assessment models suggest the need for further refinement.

CHAPTER 1

GENERAL INTRODUCTION

Preservation of natural areas within an anthropogenic landscape comes with a number of challenges for current and future generations. Among these challenges is invasive species. While there is no universally accepted definition for invasive species, they have been described as "alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (Presidential Executive Order 1999). Invasion biology is a relatively new field whose beginning is recognized in Charles Elton's *The Ecology of Invasions by Animals and Plants* (1958). Since that time, over a thousand papers have been published within the field (Richardson and Pyšek 2008).

Similar to other contemporary challenges, such as habitat alteration and climate change, the invasive species problem is global in scope and largely mediated by humans, who transport species far from their places of origin (McNeely 2001). Invasive plants, or non-native plants that spread rapidly and displace native plants, make interesting case studies because the majority of introductions are deliberate, rather than accidental (Myers and Bazely 2003, Mack and Erneberg 2002). There are several motivations for introducing non-native plants. Some plants which have become invasive, such as *Elaeagnus angustifolia* (Russian olive) and *Rosa multiflora* (multiflora rose), were originally introduced and planted for land-management purposes (Myers and Bazely 2003). Others, such as *Alliaria petiolota* (garlic mustard), were brought to North America by European pioneers for cooking or medicine (Czarapata 2005). The most common cause for introduction today, however, is use as ornamentals or in landscaping (Reichard and White 2001).

Relatively few plant introductions naturalize (escape, persist, and reproduce independently outside of human cultivation) and only a few of these become invasive in the landscape. A "tens rule" was proposed by Williamson (1996) which stated that roughly 10% of introduced species escape cultivation and that 10% of those become pests. Some data confirm these rough estimates; 5.8% to 13.4% of established non-native plants have invaded natural areas based on a study of three states (Lockwood et al. 2001). Data for woody plants in the Czech Republic suggest much smaller values; only 2.9% are known to have escaped from cultivation, with 0.4% becoming invasive (Křivánek and Pyšek 2006). However, given the magnitude of impacts for many of these plants and the number of introductions, even one invasive plant species can be a significant problem for both people and native ecosystems.

Risk analysis is a useful framework for understanding the problem of invasive plants. People have been assessing risk for a long time, but modern quantitative methods were not developed until the 1970s (Boroush 1998). Although the process is iterative, risk analysis may be conceptualized into three stages. First, the problem and its scope are defined. This provides the context for the second stage of risk assessment, where specific hazards and effects are analyzed statistically. Lastly, in risk management, propositions for dealing with the risks are weighed and a regulation strategy decided (National Research Council 2009).

With regard to problem formulation, invasive plants have many documented effects on the environment, which can be both positive and negative. Economic costs of losses, damages, and control, while difficult to evaluate accurately, have been assessed at $34.7 billion annually in the United States for invasive plants alone (Pimentel et al. 2005). Most non-native plants are deliberately introduced by the horticultural industry (Reichard and White 2011). Relatively few introduced plants naturalize and invade, and the horticultural industry as a whole is a large and profitable enterprise, with estimated outputs of $147.8 billion in 2002 (Hall et al. 2005). Invasive plants can sometimes pose direct threats to human safety by altering fire regimes; these same changes can alter the invaded native ecosystem (Brooks et al. 2004). Nutrient cycling can be changed when invasive plants are introduced into an ecosystem, which may benefit some native species while hindering others (Ehrenfeld 2003, Weidenhamer and Callaway 2010). Non-native plants generally add to overall species richness, but are often considered a threat to native biodiversity. The impacts of invasive species on native biodiversity are complicated, and some of the more dire predictions (i.e. the contribution invasive species pose to extinction, Wilcove 1998) have been recently challenged as decline of native species is often concurrent with other confounding factors, particularly habitat destruction (Powell et al. 2011, Gurevitch and Padilla 2004). Nevertheless, invasive plants can undoubtedly change the relative abundance of native species (Stinson et al. 2007, Hejda et al. 2009) and result in the creation of ‘novel ecosystems' that are game changers for conservationists and land managers (Hobbs et al. 2009).

Dealing with the consequences of invasive plants takes different forms depending on the stage of the invasion. Hulme (2006) categorizes this relationship into four stages: 1) at the point of initial introduction, the management response is prevention; 2) as the invasive plant first establishes, the management response is rapid response and eradication; 3) if the invasive plant progresses and spreads to the point that eradication is not feasible, the management response is to control and contain; and 4) if the invasive plant has progressed beyond feasible control and containment, the management response is to attempt to mitigate impacts or engage in restoration of select areas. While management at each stage presents its own set of unique challenges, given the difficulty and costs associated with management during later stages of invasion, focusing on the point of initial introduction is a logical choice.

In order to find ways to prevent the introduction of invasive plants, researchers can develop screening systems that could be used to sort potential invaders from non-invaders. Here, the process of risk assessment comes into play. There have been many studies attempting to tease out what makes certain plants invasive (reviewed in Pyšek and Richardson 2007). Many efforts have focused on which life-history traits are associated with invasiveness (e.g. Van Kleunen et al. 2010). Reproductive characteristics can influence the rate at which a newly introduced plant may spread. For example, shorter juvenile periods have been correlated with invasiveness of pines (Rejmánek and Richardson 1996) and with woody invasive plants more generally (Reichard and Hamilton 1997). Environmental factors have also been considered, such as the similarity between the plant's climate of origin and the region of introduction (Widrlechner 2001, Richardson and Thuiller 2007). These and other factors are incorporated into risk-assessment models developed to predict whether or not a particular plant is likely to naturalize or become invasive in a new environment.

Several different risk-assessment models for predicting the naturalization or invasion of plant introductions have been developed. The Australian Weed Risk Assessment (WRA) model (Pheloung 2001) has been widely used and adapted for use in different parts of the world (Daehler et al. 2004, Gordon et al. 2008, Weber et al. 2009, Gassó et al. 2010).

Additional models have been developed for China (Ou et al. 2008) and Central Europe (Weber and Gut 2004). Some models have focused on specific taxonomic groups, such as woody plants (Reichard and Hamilton 1997, Widrlechner et al. 2004, Widrlechner et al. 2009), others have incorporated biological information from the USDA Plants database (Frappier and Eckert 2003), or suggested screening based on seedling growth rate for woody plants (Grotkopp et al. 2010).

Reichard and Hamilton's (1997) continental decision tree for woody plants is of particular interest to my thesis. This tree (see Appendix A) was developed through discriminant analysis of plant characteristics associated with invasiveness and creation of classification and regression tree (CART) models. CART operates by creating a splitting rule at a parent node, which results in two child nodes. These child nodes may then become their own parent nodes with their own splitting rules, creating a dichotomously branching structure that looks like a tree (Olden et al. 2008). The splitting rules in this context are based upon characteristics associated with woody plant invasiveness. CART works well for these kinds of data, as it can handle non-parametric variables and is minimally affected by outliers (Olden et al. 2008). It can also be presented as an easy-to-understand diagram which makes it ideal for use in management contexts. It is also relatively easy to use, requiring only that one gather the needed information in the tree to reach a terminal branch and a recommendation about the non-native plant. Reichard and Hamilton's (1997) tree, like many risk-assessment models, allows for three outcomes: reject the plant, accept the plant, or study it further.

There are errors that can be associated with these outcomes: false negatives (biologically significant errors which allow potentially invasive plants past screening) and false positives (horticulturally limiting errors which prevent unlikely invaders to be introduced) (Widrlechner et al. 2004). Models tend to produce fewer false negatives than false positives (Gordon et al. 2008). Ideally, one wants to minimize errors as much as possible, regardless of type. Widrlechner et al. (2004) have suggested that in some cases, the large geographic scale that models are intended to cover can contribute to higher error rates. The process of developing regional-scale model for the Upper Midwest has been an ongoing project (Widrlechner et al. 2009).

This process began with the development of risk-assessment models specific to Iowa for woody plants (Widrlechner et al. 2004). Two models were designed based on the continental decision tree (Reichard and Hamilton 1997), which itself had a poor classification rate and a relatively high horticulturally limiting error rate when applied to a test set in Iowa (Widrlechner et al. 2004). A key component of these two models (called 'modified decision tree' and 'decision tree/matrix model') was the incorporation of information about the environmental conditions where the plant is native. This manifested as the geographic-risk value (G-value) (Widrlechner et al. 2004). The G-value for a plant is determined by calculating the proportion of naturalizing to non-naturalizing species in each geographic subdivision of that plant's native range; these are then averaged to create the G-value, which ranges from zero to one (Widrlechner et al. 2004). A zero means that the plant does not come from a region that has produced known naturalizers, and a one means that all plants introduced and cultivated from that plant's native range have naturalized (although G-values are typically below 0.6).

In addition to G-values, an additional trait was included because of its significance in the fragmented Iowa landscape: fleshy, bird-dispersed fruits (Widrlechner et al. 2004). Many of the most successful invasive woody plants have this trait (i.e. *Morus alba, Lonicera tatarica, Rhamnus cathartica*), and dispersal of seed by animals is widely recognized as an important facilitator of plant invasions (Richardson et al. 2000). The two models based on Reichard and Hamilton's (1997) continental decision tree both focused on the branches of the tree that produced the most errors for Iowa. A third model, the CART model (see Appendix A), was also developed independently of the continental decision tree (Widrlechner et al. 2004). Each of these models follows primarily a dichotomously branching scheme.

In addition to developing risk-assessment models, validating them after they have been designed is an important step. There are three general approaches to model validation. (1) During model development, re-sampling techniques serve as a form of internal validation. After models are developed, they may be externally validated with a new data set from (2) the same region, or (3) a different region (Widrlechner et al. 2009). Following validation, modifications can be made to risk-assessment models so they better fit the intended region of use. The Australian WRA in particular has been adapted many times in this manner (e.g.

Daehler et al. 2004). In addition to validation of existing models, new models may be developed to increase model power and accuracy. Classification and regression trees have often been used to develop risk-assessment models (Reichard and Hamilton 1997, Widrlechner et al. 2004), but have important limitations. CART trees are inherently unstable: when splitting rules and their nodes are created, they are based upon the species available in the training set (the initial list of species). Small changes to this training set can significantly influence how splits and nodes are made (Olden et al. 2008). This becomes more pronounced further down the tree where splits are based on progressively smaller sample sizes. This also means that the decision tree created from the training set is not necessarily the optimal tree, suggesting that both classification and error rates could be improved by other statistical techniques (Olden et al. 2008). Random forest modeling (Brieman 2001) addresses both of these problems by creating many CART trees based on permutations of the training set and then averaging them. This approach has not yet been widely applied to invasive plant risk-assessment models and may help improve their power and accuracy.

Risk analysis does not end with the production of models. The nature of their final implementation – which is part of risk management – depends upon the cooperation of a variety of stakeholders. Therefore, considering the perspectives of these stakeholders on invasive plants and risk-assessment models as a management tool is an important component of the risk analysis process. Incorporating the human dimension into risk analysis is important for more than just this reason. Many factors associated with plant invasions are directly linked to people, such as propagule pressure (Colautti et al. 2006) and marketing time (Pemberton and Liu 2009). Some traits selected for ornamental uses of plants and their commercial production also coincide with traits that may contribute to invasiveness (White and Schwartz 1998).

There are many potential stakeholders who should be involved in the risk analysis process for invasive plants. Some groups are intuitive: land managers charged with protecting natural areas from invasive plants and horticulturists who are frequently responsible for non-native plant introductions. Invasive plants are often a major bane for conservationists and land managers nationwide, and these stakeholders have a vested interest in minimizing introduction or impacts of new invaders. The nursery industry (horticulture) on the other hand has a vested interest in bringing new and interesting plants to the market. This appears to set up a strong conflict between the two stakeholder groups, but previous work indicates that horticulturists are not insensitive to conservation needs (Peters et al. 2006, Burt et al. 2007) and some botanical gardens are actively taking responsibility by using risk-assessment models (Jefferson et al. 2004). In addition, two other groups stand out as having a strong interest in the outcomes of risk-assessment models: private woodland landowners and gardeners. Particularly for those who own large tracts of land not under cultivation, the impact of invasive plants can be a burden. Gardeners too would be impacted by the application of risk-assessment models, as they could limit their choices in the marketplace.

Regardless of group, decision-making regarding the issue of invasive plants involves personal value judgments. Some stakeholders may value native biodiversity and want to protect it from the negative impacts of invasive plants, but others may not share these values and instead operate under a different set of personal rules. Understanding the range of stakeholder perspectives on invasive plants can involve more than just querying attitudes about the topic itself, but also attempting to understand underlying conceptual models. These mental maps act as both references and filters for new experiences (Reaser 2001), so they influence an individual's attitudes or values.

An individual's sense of their relationship with nature comes to mind as one immediately relevant to how one might respond to the issue of invasive plants. Disconnection from the natural world has been widely argued as a contributing factor to our continued inaction about and ignorance of environmental problems (Leopold 1949, Naess 1973, Roszak et al. 1995, Staples 2001, Pyle 2003). Several scales have been developed to assess a person's relationship with nature (Dunlap et al. 2000, Schultz 2000, Schultz 2001, Mayer and Frantz 2004, Nisbet et al. 2009, Perkins 2010), but not all of them aim to capture the more holistic, 'ecological self', or if they do, they neglect the physical aspects of the human-nature relationship and frame it as strictly cognitive or emotional.

Nisbet et al. (2009) created a scale that addressed both the holistic concepts of self-identification with nature and physical relatedness to it. Their questions are divided among three subscales: NR-Self, NR-Perspective, and NR-Experience. NR-Self relates to how nature is considered to be a component of self-identity. NR-Perspective captures a person's sense of the human impacts on nature and is more external in orientation. Lastly, NR-Experience reflects physical familiarity with and enjoyment of nature (Nisbet et al. 2009). These factors together form a comprehensive nature relatedness score. Investigating whether or not this particular construct factors into individual decisions about invasive plants is of relevance to understanding stakeholder perspectives; managing invasive plants inevitably involves managing and understanding people (Reaser 2001). As a whole, the objective of this thesis is to address the various aspects of risk analysis for invasive plants, as elaborated below.

Study Objectives

There were four primary objectives of this research:

1. Validate risk-assessment models previously developed for Iowa (Widrlechner et al. 2004) with a new set of non-native woody plants cultivated in the state.
2. Test the performance of a random forest model on the original list of 100 woody plants in Iowa (in Widrlechner et al. 2004) and validate it with the new set of non-native woody plants developed for objective one.
3. Survey the perspectives of four important stakeholder groups on invasive plants, invasive plant management, and risk-assessment modeling.
4. Examine the relationship of the survey responses above to stakeholder's nature relatedness (Nisbet et al. 2009).

Thesis Organization

There are four major sections in this thesis. Chapter 1 is this general introduction. Chapter 2 is a manuscript entitled "Performance of five models to predict the naturalization of non-native woody plants in Iowa" and covers the first two study objectives listed above. Chapter 3 is a manuscript entitled "Assessing stakeholder perspectives on invasive plants to inform risk analysis" and covers the last two study objectives listed above. Chapter 4 is the general conclusion.

Author Contributions

All preparation of this text was the responsibility of the candidate. Drs. Jan Thompson and Mark Widrlechner assisted with revision and editing.

The concept and experimental design of the research in Chapter 2 is based on a research proposal by Drs. Mark Widrlechner, Jan Thompson, Philip Dixon, and Jeffery Iles. Collection of species data and validation runs for four models were the responsibility of the candidate. Philip Dixon handled analysis of statistical significance and the development of the random forest model. Data interpretation was a collaborative effort among all coauthors. Writing of the manuscript was the responsibility of the candidate.

The concept and experimental design of the research in Chapter 3 was the responsibility of the candidate, with primary assistance from Jan Thompson and input from all other committee members. Survey administration, analysis, and data interpretation was the responsibility of the candidate, and guided by Jan Thompson and Mark Widrlechner. Writing of the manuscript was the responsibility of the candidate.

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CHAPTER 2

PERFORMANCE OF FIVE MODELS TO PREDICT THE NATURALIZATION OF NON-NATIVE WOODY PLANTS IN IOWA

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Abstract

Use of risk-assessment models that can predict the naturalization and invasion of non-native woody plants is a potentially beneficial approach for protecting human and natural environments. This study validates the power and accuracy of four risk-assessment models previously tested in Iowa, and examines the performance of a new random forest modeling approach. The random forest model was fitted with the same data used to develop the four earlier risk-assessment models. The validation of all five models was based on a new set of 11 naturalizing and 18 non-naturalizing species in Iowa. The fitted random forest model had a high classification rate (92.0%), no biologically significant errors, and few horticulturally limiting errors (8.7%). Classification rates for validation of all five models ranged from 62.1 to 93.1%. Horticulturally limiting errors for the four models previously developed for Iowa ranged from 11.1 to 38.5%, and biologically significant errors from 4.2 to 18.5%. Because of the small sample size, few results were significantly different from the original tests of the models. Overall, the random forest model shows promise for powerful and accurate risk-assessment, but mixed results for the other models suggest a need for further refinement.

Significance to Nursery Industry

Nursery and landscape professionals introduce many new non-native plants, but sometimes these introductions escape from cultivation, naturalize, and invade. This is a concern to many stakeholders, from members of the nursery industry itself to land managers who must deal with invasive species encroaching on natural areas. As new plants continue to be introduced, there is the possibility of inadvertently ushering in new invasive plants. Given the many benefits of introducing new plants, researchers have worked to develop methods to

discern potential invaders from benign introductions through risk-assessment modeling. Plants screened by these models are then recommended for acceptance, rejection, or further study based on plant attributes, such as life-history traits or geographic origin. Errors produced by risk-assessment models represent potential costs, both biologically and horticulturally. This paper focuses on the validation of four existing risk-assessment models for woody plants in Iowa, and the application and validation of a new (and potentially more accurate) "random forest" modeling technique to predict naturalizing and non-naturalizing plants. Validation, which represents a "real world" test of the models, indicates that there is room for improvement in their power and accuracy. The new random forest modeling technique shows promise for the future development of a regional-scale model for the Upper Midwest.

Introduction

The migration of species across the globe is a natural process, but humans are able to disperse and spread organisms much more quickly and extensively than any other species. Sometimes migrants are moved by accident, but people often deliberately introduce and spread species far beyond their native ranges. For the most part, human movement of plants is deliberate rather than accidental (Mack and Erneberg 2002), and the horticultural industry is recognized as a major influence on this phenomenon (Reichard and White 2001, Dehnen-Schmutz et al. 2007, Dawson et al. 2008). Most introduced plants are benign and benefit human interests. Sometimes introduced plants will thrive in their new environment and are able to sustain populations without human assistance. A few of these do so well that they begin to aggressively displace native vegetation and alter local ecosystems. This unintended consequence of introducing new plants beyond their original native ranges causes undesirable changes to our landscapes (Mack et al. 2000) and is costly to manage (Pimentel et al. 2000, Pimentel et al. 2005).

In order to prevent these consequences, screening new plants for invasiveness before introduction may be an effective strategy with net bioeconomic benefits (Keller et al. 2007). This has led to the development of statistical models to evaluate the probability that a non-native plant will naturalize or invade in a new location. Information, such as life-history characteristics of plants that are associated with invasiveness, is typically included; pertinent geographic or climatic variables are often factored in as well (White and Schwartz 1998, Reichard 2001, Widrlechner et al. 2004, Richardson and Thullier 2007). Several models have been developed and are based on different kinds of statistical procedures, such as classification and regression trees (Widrlechner et al. 2004), discriminant analyses (Reichard 2001), and analytic hierarchy processes (Ou et al. 2008). Some take the form of a scoring system, such as the Australian Weed Risk Assessment (Pheloung 2001), and others are decision trees (Reichard and Hamilton 1997, Widrlechner et al. 2004).

Existing models usually assign a plant one of three screening outcomes: 'accept' if the plant is at low risk of becoming invasive, 'reject' if the plant is at high risk of becoming invasive, and 'further analysis' where the model is unable to make a clear determination. Power and accuracy of the models can be assessed by testing known invaders and non-invaders (Jefferson et al. 2004, Křivánek and Pyšek 2006, Widrlechner et al. 2009). Classification rates (which determine the "power" associated with the models) are based on the proportion of species a model classifies, and should ideally be high, given the time and expense of reassessing 'further analysis' outcomes (White and Schwartz 1998). Models may also produce two types of errors (which reflect their "accuracy"): (1) false positives, or horticulturally limiting errors which incorrectly reject a plant that actually has a low risk of becoming invasive, and (2) false negatives, or biologically significant errors which incorrectly accept a plant that has a high risk of becoming invasive (Widrlechner et al. 2004). Given the potential costs associated with these errors, researchers continue to test, validate, and improve risk-assessment models to minimize these problems.

One way of improving models is to tailor them to more specific geographic regions. Risk-assessment models for woody plants, in particular, may benefit from this approach, because of the importance of local climatic and edaphic conditions in influencing woody-plant survival (Widrlechner 1994, Widrlechner 2001). Widrlechner and Iles (2002) established a list of 100 non-native woody plants cultivated in Iowa that were either naturalized (28 species) or non-naturalized (72 species). This plant list was used to test an existing continental-scale model (Reichard and Hamilton 1997) and generate three new models to predict the likelihood that these species would escape from cultivation and potentially become invasive in Iowa (Widrlechner et al. 2004). Model validation can be done internally during model development, but can also be done externally by testing a new data set from the same region or from a similar region. The models from Widrlechner et al. (2004) were externally validated by using independent datasets for non-native woody plants from the Chicago region with mixed results (Widrlechner et al. 2009).

A second way to improve the overall performance of risk-assessment models is to apply different statistical techniques that may yield better power and accuracy. Classification and regression tree (CART) approaches have previously been used to develop risk-assessment models (e.g. Reichard and Hamilton 1997) with some success, but they have some inherent limitations. CART trees differentiate species within a data set by using a series of dichotomous branches based on classification rules derived from a training data set (e.g. an initial list of naturalizing and non-naturalizing species). Each subsequent decision node (which is based on a classification rule) is developed with a progressively smaller sample size. This makes the classification rules for nodes further down the tree very sensitive to small changes in the training data set, generating high variance. A newer statistical approach, random forest modeling (Brieman 2001), can reduce this variance by averaging many classification trees based on small perturbations of the original data. In this way, the small sample sizes used to determine terminal classification rules become less of an issue, because the list of species used to make this rule is subject to additional randomization.

Random forest models have been documented as more robust and more accurate than CART models (Hastie et al. 2009). Specific applications in ecology have also revealed its potential. Cutler et al. (2007) reviewed this topic and included an example for invasive species; they tested four different classification methods (including CART) in predicting the presence of four invasive plant species and found that a random forest approach outperformed the other methods in most accuracy measures. Similarly, Williams et al. (2009) tested several classification schemes for their ability to predict occurrences of rare plants and found that random forest models produced the best fit. Classification was also strong for random forest compared to other classification models when modeling abundance changes in a bird population (Kampichler et al. 2010). Collectively, these suggest that a random forest approach may be valuable for developing risk-assessment models to predict the naturalization of non-native woody plants.

Our research objectives were twofold. First, motivated by mixed results for external validation of the Iowa models (Widrlechner et al. 2004) when tested with Chicago-region datasets (Widrlechner et al. 2009), we were interested in validating them by using a dataset that more closely matched the region of model development (Iowa). Second, we conducted a new investigation of the performance of the random forest approach for use as a risk-assessment model to predict naturalization of woody plants in Iowa.

Materials and Methods

We began by generating a list of non-native woody plant species cultivated in Iowa, not included in Widrlechner et al. (2004), that could be clearly assigned to categories either as naturalizing or non-naturalizing in the study area. New naturalizing species were determined by examining herbarium vouchers which had not been collected or available when the previous list was made (Widrlechner and Iles 2002). Additional non-naturalizing species were suggested by the authors and Jeffery Iles; herbarium records were checked for these species to confirm that they had not naturalized. Both lists were then examined for accuracy and completeness by individuals experienced with the Iowa flora (Deborah Lewis, Jimmie Thompson, Cathy McMullen, and Mark Vitosh). This process resulted in a list of 29 additional non-native woody species cultivated in Iowa. Of these, 11 species have naturalized and 18 have no evidence of naturalization in Iowa.

For each of these 29 species, data on life-history characteristics (Table 1) and native ranges required by the models were compiled. These data were obtained from previous work and several published and online sources (Dirr 1998, Randall 2003, U.S. Department of Agriculture 2008, Widrlechner et al. 2009) with additional review by the authors and professionals with experience cultivating these plants. The native ranges of the 29 species across 278 geographic subdivisions were used to calculate geographic-risk values (as per Widrlechner et al. 2004). Native range data were primarily obtained from the USDA-ARS Germplasm Resource Information Network database (U.S. Department of Agriculture 2010) and previous data from the Chicago study (Widrlechner et al. 2009), with supplementation from published floras (Komarov 1934-1964, Tutin et al. 1964-1994, eFloras 2010). Geographic risk values (G-values) for these species were calculated on the basis of the proportion of species native to a geographic subdivision that have naturalized in Iowa, as described by Widrlechner et al. (2004). These proportions were already determined for nearly all geographic subdivisions in our current study. In those few cases (approximately 7% of 1000 data cells) where we found a plant occurring in a geographic subdivision that had not been treated by Widrlechner et al. (2004), values based on neighboring or similar subdivisions were used if available, or the field was considered as missing data.

These data were collected and reviewed and then the four risk assessment models described in detail by Widrlechner et al. (2004, 2009) were applied to the 29 new species. These models included Reichard & Hamilton's 'continental decision tree' (1997) and three additional models developed specifically for Iowa: (1) the 'modified decision tree' which adds ten steps to the continental decision tree, (2) the 'decision tree/matrix model' which focuses on reevaluating the 'further analysis' species produced by the continental decision tree, and (3) the 'CART model' developed specifically for the original Iowa data set and based on a classification and regression tree (CART).

In addition, a new random forest model was created based on the dataset of 100 species from the original Iowa study (Widrlechner and Iles 2002; Widrlechner et al. 2004). A random forest (Breiman 2001, Cutler et al. 2007) is an extension of a CART model. Because a CART model partitions a data set into smaller and smaller subsets, predictions are quite variable because many splits are based on small numbers of observations. Random forest models reduce the variance of predictions by constructing many CART trees within the model and then averaging the results among them. Because the reduction in variance is greater when predictions are independent, the random forest algorithm includes a step to reduce positive correlations among predictions.

In detail, the random forest algorithm includes:

1) Drawing a non-parametric bootstrap sample (Dixon 2002) of the observations. Some observations are omitted from the bootstrap sample, some observations occur once, and others are repeated multiple times.

2) Constructing a CART model based on the bootstrap data. At each potential split, a randomly selected subset of the variables is evaluated to define a split. This random selection of variables reduces the positive correlation among predictions and improves the precision of the prediction.
3) Calculating the probability of naturalization for each observation in the bootstrap sample.
4) Repeating steps 1 through 3 for 1000 bootstrap samples.
5) Calculating the average probability of naturalization for an observation by averaging predictions for that observation in all CART trees.

A fitted random forest model was created based on the original 100 Iowa species generated from 1000 CART trees. The probability of not naturalizing was set equal to 0.72, the proportion of species without evidence of naturalizing in the original 100-species data set for Iowa.

The fitted random forest was used to predict the probability of naturalization for each of the 100 species in the training data set (the species list used to develop the model) and for each of the 29 new species. The classification of species as 'accept', 'reject', or 'further analysis' was based on the predicted probability of naturalization. Comparing the predicted probabilities to the observed status of each of the 100 species in the training data set supported the following classification rule:

If the predicted probability is < 0.12, then classify as 'accept';
If the predicted probability is ≥ 0.28, then classify as 'reject'; and
If the predicted probability is between 0.12 and 0.28, classify as 'further analysis'.

The power and accuracy of each model was assessed in the following manner. First, we examined the 'classification rate,' or the proportion of species successfully assigned 'accept' or 'reject' by the models. We also assessed two types of errors, the 'horticulturally limiting error' and 'biologically significant error', expressed as the proportion of error to the total number of classified species (as per Widrlechner et al. 2004, 2009).

The statistical significance of differences in classification rates among models was assessed by reducing the classification of species to two groups: successfully classified or further analysis. The null hypothesis that all five models had the same probability of successfully classifying a species was tested with a Cochran-Mantel-Haenzel test for stratified categorical data (Fleiss 1981), with each species considered a unique stratum. This statistical test accounts for species-species differences in ease of classification. When the Cochran-Mantel-Haenzel test was significant, individual models were compared to the average performance to identify which models performed better or worse than average. Because each stratum had at most five observations (one per method), p-values for all statistical tests were computed by randomization within strata, using 999 permuted data sets.

The statistical significance of differences in horticulturally limiting errors and biologically significant errors was assessed by reducing the classification to 'accept' or 'reject' and treating all 'further analysis' results as missing values. The random alteration of each species only permuted 'accept' or 'reject' values to the classified observations, i.e. the missing values were not permuted. This approach compares the probability of a biological or horticulturally limiting error among models when the method classified a species. Statistical significance of the differences in classification and error rates between old and new data sets was assessed with the Fisher exact test for 2×2 tables (Fleiss 1981). All statistical computations were done with R statistical software (R Development Core Team 2011).

Results and Discussion

Performance of the four original models on 29 new species. The set of four models tested previously (Widrlechner et al. 2004) had variable performance when applied to the new set of 29 Iowa species. Classification rates ranged from 62.1 to 93.1% (Table 2), which is comparable to classification rates for other types of models (i.e. Gordon et al. 2008, Křivánek and Pyšek 2006, Jefferson et al. 2004). Comparing classification rates for the 29 new species to the original 100 species, the continental decision tree performed better for the new species ($P < 0.01$) and the CART model performed worse ($P < 0.05$); other classification rates did not differ significantly.

Two of the models are based on modifications to the continental decision tree. The refinements of the modified decision tree were designed to focus on the branch of that decision tree that produced the most errors and 'further analysis' outcomes (Widrlechner et al. 2004). Given that nine out of the ten species producing horticulturally limiting errors in the new set of 29 Iowa species came from the branch targeted by the modified decision tree model, this new test set underscores the importance of this step. However, its ability to produce improvements was mixed. While there was a reduction in horticulturally limiting errors, two species generated biologically significant errors (Table 2). The second model based on the continental decision tree – the decision tree/matrix model – focused on reanalyzing 'further analysis' species. Given the high initial classification rate of the continental decision tree for the 29 new Iowa species, there was little room for improvement. One species (*Lonicera sempervirens*) was treated differently between these models, and it became a biologically significant error. The CART model, which is not related to the continental decision tree, had a much lower classification rate but, to its credit, it displayed the best (lowest) horticulturally limiting error rate (Table 2). It also had a higher biologically significant error rate, though it misclassified the same number of species (three) as did the continental decision tree.

Differences in error rates between the original 100 species and the 29 new species were not statistically significant (probably due to the small sample size of the new species data) with one exception: the horticulturally limiting error rate for the continental decision tree was worse for the new species tested ($P < 0.02$). Both types of error rates for the four original models were, however, higher than for the original 100 species, ranging from 11.5 to 18.5% for biologically significant errors and from 11.1 to 38.5% for horticulturally limiting errors (Table 2). They are also higher than error rates reported in the Chicago study (Widrlechner et al. 2009) or for many tests of other risk-assessment models, such as the Australian WRA (see Gordon et al. 2008 for a meta-analysis). Similar to results reported by Widrlechner et al. (2009), the CART model had the lowest horticulturally limiting error rate of the four, which is encouraging given that many other risk-assessment models generate few biologically significant errors at the expense of more horticulturally limiting errors.

The high error rates overall are not surprising given the nature of the data set. These 29 species represent, in many respects, a 'real world' test in that they do not conform to the 0.28 ratio of naturalizing species to non-naturalizing species under which three of the four models were developed (Widrlechner et al. 2004). Models should ideally be robust enough to perform well under deviations from this ratio, such as the 0.38 ratio that we observed for the 29 new Iowa species. There are also idiosyncrasies that arise from the list of plants themselves. This pool of naturalizing species is different in some important ways. Since these species are based on newer records of naturalization, there are fewer 'major invaders' of Iowa than were included in the list used to develop the models. Křivánek and Pyšek (2006) have suggested that woody plant risk-assessment models are generally better at pinpointing strongly invasive species than at sorting out those which have only begun to naturalize.

Certain species tended to produce errors across all four of the models. In each of the models, *Frangula alnus* and *Rhamnus utilis* generated biologically significant errors; *Rhamnus davurica, Acer platanoides* and *Lonicera sempervirens* were other common sources of errors. Two species also generated horticulturally limiting errors in all four models: *Prunus cerasifera* and *Salix caprea*. Other common horticulturally limiting errors, generated by three models, were *Buddleja davidii, Clematis ternifolia, Cotoneaster divaricatus, Cotoneaster horizontalis,* and *Hedera helix* (each of these four species also produced errors in the Chicago-region study of Widrlechner et al. 2009). There is always the possibility that species that are presently categorized as horticulturally limiting errors will naturalize in the future, due to the considerable lag-time between introduction and naturalization for woody plants (Pyšek and Prach 1993, Crooks 2005). Two of these species (*Buddleja davdii, Clematis ternifolia*) are known to have naturalized in northern Missouri and could conceivably do the same in Iowa in the coming decades. Overall, the performance of these four models on the test set of 29 new Iowa species resulted in disappointing error rates, highlighting the need for continued model development.

Performance of the random forest model. The fitted random forest model, which is the product of 1000 decision trees trained on the original 100 Iowa species, performed well overall. Classification rates (Table 2) were significantly better than the average rate for all other models ($P = 0.002$). The biologically significant error rate was zero and also significantly better than the average of all other models ($P = 0.018$). At the same time, the fitted random forest model was able to discern non-naturalizing species better than three of the other models ($P = 0.092$), but of the five models, the CART model produced the fewest horticulturally limiting errors ($P = 0.016$). Although the fitted random forest model was not the best for horticulturally limiting errors, it still performed well overall, confirming the strength of random forest modeling when applied to risk-assessment for non-native woody plants. It also performs well compared against the classification and error rates of other risk-assessment models in the literature (i.e. Jefferson et al. 2004, Křivánek and Pyšek 2006, Gordon et al. 2008).

Validation of the fitted random forest model based on the 29 new Iowa species was somewhat less impressive, but still promising. The classification rate dropped, but was not different from the average of the other models tested on the same set of species ($P = 1.012$). Of the five models, the fitted random forest model had the lowest biologically significant error rate (Table 2), although it was not significantly different from the others (again, perhaps because of the small sample size). Application of the fitted random forest model to the 29 new species produced a greater percentage of horticulturally limiting errors, but relative to the other models it ranked second ($P = 0.092$); the previously-developed CART model performed better for classifying non-naturalizing species correctly ($P = 0.016$).

The development process for the fitted random forest model allows for an analysis of the relative importance of each variable included in the model (Figure 1). Geographic-risk values and rapid maturation were the two most important characteristics for determining the ability of a plant to naturalize in Iowa, followed by whether it is invasive outside North America and has fleshy, bird-dispersed fruits. The importance of these variables in the random forest model may also help explain some of the strengths of the CART model in this and in previous studies (Widrlechner et al. 2004, Widrlechner et al. 2009), since the CART model includes only G-values, quick maturity, and fleshy, bird-dispersed fruits as predictive variables.

General conclusions. The relatively high classification rate (82.8%) of the random forest model indicates that it may be a promising approach for predicting naturalization of non-native woody plants. It does, however, have some drawbacks that may limit its use by those responsible for screening non-native plants for invasiveness. Because a fitted random forest model is the product of many decision trees, it cannot be presented as a single, easy-to-understand diagram like the other four models. It becomes a 'black box' where data go in and recommendations mysteriously emerge, and it requires advanced technical skill to use. It is here where the other models, in spite of their mixed performance during validation, have an advantage. Their implementation is easier for users than are the products of the random forest technique.

We know from surveys of stakeholders on risk-assessment models in Iowa that there is a preference for low biologically significant error rates, and that such errors should not exceed 10% (Kapler et al. 2011). This makes the random forest model the only acceptable choice to these groups, based on the external validation of the 29 new species. However, validation of the random forest model exceeded the 20% upper limit for horticulturally limiting errors (Kapler et al. 2011); only the CART model fit this limit for the 29 new species (Table 2). Horticulturally limiting error rates always need to be interpreted with care, as some apparent errors may forecast future naturalization events. Even if some of these errors may be explained by idiosyncrasies in the species list or the likelihood of future naturalization, there is still a need to reduce this type of error in the random forest model. To this end, we intend to complete additional validations of these risk-assessment models on two additional data sets from the Upper Midwestern United States, one from northern Missouri and the other from southern Minnesota. Our ultimate goal is to produce a regional model for the naturalization of non-native woody plants that is more accurate, powerful, and easy to use than those currently available.

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Table 1. Characteristics of 29 new non-native woody landscape plants in Iowa used to test models to assess the risk of naturalization in Iowa.

Species	Naturalized	G^z	Invades outside North America	Requires germination pretreatment	Group invasive in North America	Quick maturity	Sterile hybrid	Quick vegetative spread	North American native	Evergreen foliage	Fleshy, bird-dispersed fruits
Acer palmatum Thunb.	N	0.315	Y	Y	N	N	N	N	N	N	N
Amelanchier canadensis (L.) Medik.	N	0.055	N	Y	Y	Y	N	N	Y	N	Y
Buddleja davidii Franch.	N	0.260	Y	N	N	Y	N	N	N	N	N
Buxus sempervirens L.	N	0.443	N	Y	N	N	N	N	N	Y	N
Castanea dentata (Marshall) Borkh.	N	0.071	N	Y	N	N	N	N	Y	N	N
Clematis ternifolia DC.	N	0.373	N	Y	N	Y	N	Y	N	N	N
Cotoneaster divaricatus Rehder & E.H. Wilson	N	0.339	Y	Y	Y	Y	N	N	N	N	Y
Cotoneaster horizontalis Decne.	N	0.257	Y	Y	Y	N	N	N	N	N	Y
Fothergilla gardenii L.	N	0.110	N	Y	N	N	N	N	Y	N	N
Hedera helix L.	N	0.504	Y	Y	N	N	N	Y	N	Y	Y
Picea abies (L.) H. Karst	N	0.491	N	N	N	N	N	N	N	Y	N
Pinus sylvestris L.	N	0.444	Y	N	N	N	N	N	N	Y	N
Platycladus orientalis (L.) Franco	N	0.367	N	Y	N	N	N	N	N	Y	N
Prunus cerasifera Ehrh.	N	0.430	Y	Y	Y	Y	N	N	N	N	Y
Salix caprea L.	N	0.452	Y	N	Y	Y	N	N	N	N	N
Syringa pubescens Turcz. subsp. *patula* (Palib.) M.C. Chang & X.L. Chen	N	0.421	N	N	Y	N	N	N	N	N	N
Taxodium distichum (L.) Rich.	N	0.152	N	Y	N	N	N	N	Y	N	N
Wisteria floribunda (Willd.) DC.	N	0.339	Y	N	Y	N	N	Y	N	N	N
Acer platanoides L.	Y	0.485	Y	Y	N	N	N	N	N	N	N
Celastrus orbiculatus Thunb.	Y	0.367	Y	Y	N	Y	N	Y	N	N	Y
Frangula alnus Mill.	Y	0.439	N	Y	N	N	N	N	N	N	Y
Ligustrum obtusifolilum Siebold & Zucc.	Y	0.359	Y	Y	Y	Y	N	N	N	N	Y
Ligustrum vulgare L.	Y	0.453	Y	Y	Y	Y	N	N	N	N	Y
Lonicera japonica Thunb.	Y	0.318	Y	Y	Y	Y	N	Y	N	SEMI	Y
Lonicera morrowii A. Gray	Y	0.343	N	Y	Y	Y	N	N	N	N	Y
Lonicera sempervirens L.	Y	0.142	N	Y	Y	Y	N	Y	Y	N	Y
Rhamnus davurica Pall.	Y	0.469	N	Y	N	N	N	N	N	N	Y
Rhamnus utilis Decne.	Y	0.288	N	Y	N	N	N	N	N	N	Y
Rubus caesius L.	Y	0.484	Y	Y	Y	Y	N	Y	N	N	Y

[z] Geographic-risk value, a ratio that can vary between zero and one (see Materials and Methods).

Table 2. Summary of classification and error rates for five risk-assessment models by data set.

Model	Classification rate (%)	Biologically significant error rate (%)	Horticulturally limiting error rate (%)
Continental decision tree			
Original 100 Iowa species	65.0	3.1	16.9
New 29 Iowa species	89.7	11.5	38.5
Modified decision tree			
Original 100 Iowa species	90.0	3.3	13.3
New 29 Iowa species	93.1	18.5	29.6
Decision tree/matrix model			
Original 100 Iowa species	85.0	3.5	16.4
New 29 Iowa species	93.1	14.8	37.0
CART model			
Original 100 Iowa species	81.0	2.5	3.7
New 29 Iowa species	62.1	16.7	11.1
Random forest model			
Original 100 Iowa species	92.0	0.0	8.7
New 29 Iowa species	82.8	4.2	29.2

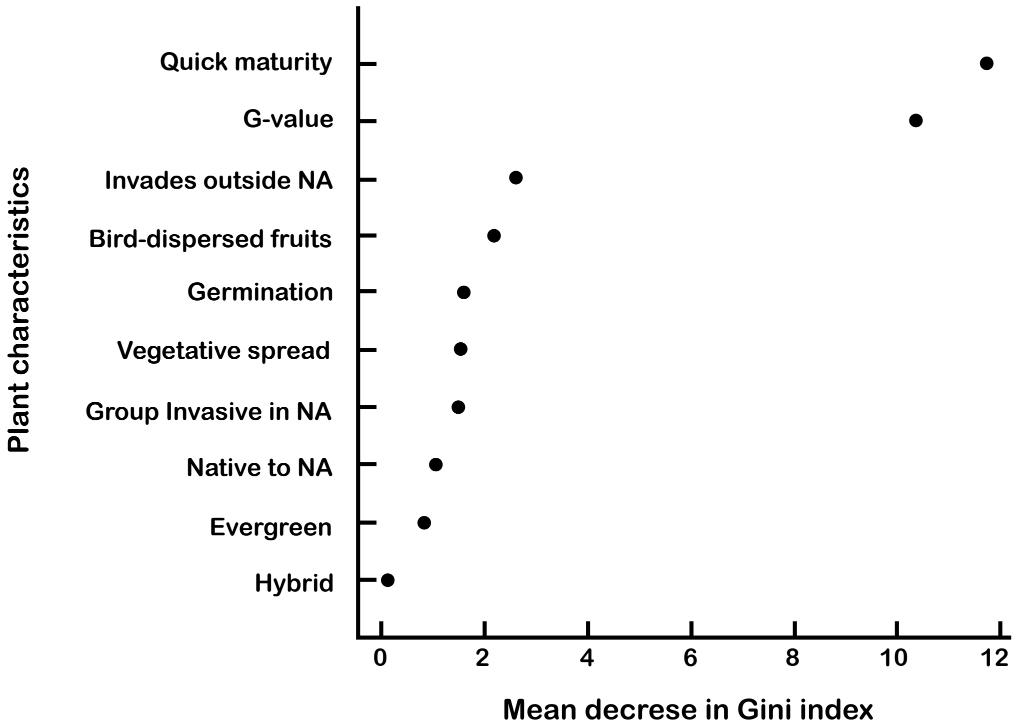

Figure 1. Variable importance in the random forest model based on 100 Iowa species (Widrlechner et al. 2004).

CHAPTER 3

ASSESSING STAKEHOLDER PERSPECTIVES ON INVASIVE PLANTS TO INFORM RISK ANALYSIS

A paper to be submitted to *Invasive Plant Science and Management*

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Abstract

Conservation and land management efforts are often based primarily on natural science, but could be more successful if the human element were effectively integrated into decision-making. This is especially true for efforts to control invasive plants, whose arrival is usually the product of deliberate human introduction. Risk-assessment models that predict the probability that a non-native plant will naturalize or invade are useful tools for managing invasive plants. However, stakeholders could be affected differently by decisions based on such models. We surveyed the attitudes of four stakeholder groups (conservation professionals, master gardeners, professional horticulturists, and woodland landowners) in Iowa about invasive plants, general management approaches, and risk-assessment models. We also examined whether or not a stakeholder's nature relatedness plays a role in shaping his or her responses. Stakeholder perceptions varied less than expected across all four groups. Eighty-seven percent of respondents agreed invasive plants are a problem, and 88.4% agreed that we have a responsibility to manage them to protect natural areas. Support for the use of risk-assessment models is also high, with 78.7% of respondents agreeing their use has potential to prevent plant invasions. Nature relatedness scores for all groups were correlated with respondent perspectives on invasive plants. Respondents believe biologically significant errors (errors that may introduce a new invasive plant) should not exceed 5% to 10%. Respondents were more tolerant of horticulturally limiting errors (errors that restrict sale/use of a plant that would not have become invasive), reporting rates of 10% to 20% as acceptable. Researchers developing risk-assessment models should aim for error rates within these bounds. General agreement among these stakeholder groups indicates potential support for risk management efforts.

Interpretive Summary

Many conservation professionals, land managers, and stewards have spent countless hours containing or eradicating invasive plants encroaching on natural areas. Given the costs and effort associated with their control, prohibiting the introduction of new non-native plants likely to become invasive would be very beneficial. Risk-assessment models are statistical tools that can be used to screen new plant introductions for invasiveness, but implementing these models comes with challenges. Since most new plant introductions are deliberately initiated by humans, stakeholders' needs must be taken into consideration if these pre-emptive management efforts are to be successful. We identified and surveyed four stakeholder groups (conservation professionals, master gardeners, professional horticulturists, and woodland landowners) in Iowa, who are important voices in decision-making for invasive plants, about their perspectives on general management approaches, and risk-assessment models. We also examined whether or not nature relatedness (a person's sense of connection to the natural world) plays a role in shaping these perspectives. We found these stakeholder groups had relatively minor differences of opinion. Stakeholders agreed that invasive plants were a problem that we have a responsibility to manage, and were open to the idea of passing state laws or mandates to achieve that goal. This was true even of professional horticulturists and master gardeners, who would potentially incur more costs than benefits from such regulations. Stakeholders also displayed consistently high levels of nature relatedness, and concern these groups have about invasive plants may be influenced by their identification with nature. Overall, these are encouraging signs that risk analysis to limit introduction of potentially invasive plants will be acceptable in Iowa. When selecting a risk-assessment model to adopt, stakeholders believe choosing models with a low chance of introducing a potentially invasive plants is more important than choosing models with a low chance of prohibiting a plant unlikely to become invasive. Current risk-assessment models, which emphasize prevention of invasive plant introduction at the expense of preventing introduction of benign plants, concur with stakeholder preferences.

Introduction

Invasive plants, or non-native plants that spread aggressively into natural habitats and disrupt native communities, are commonly named as one of the most problematic conservation challenges today. In addition to the $35 billion annually in economic costs that they incur (Pimentel et al. 2005), invasive species can reduce native biodiversity (Hejda et al. 2009) and alter ecosystem processes (Ehrenfeld 2003; Brooks et al. 2004). Many strategies have been suggested to confront this challenge, including preventing introduction of invasive plants, responding rapidly to their establishment, containing their spread, and mitigating their impacts (Hulme 2006). Often, land managers responsible for maintaining natural areas are left in crisis-management mode and must contain invaders or mitigate their impacts in costly battles. It would be better to prevent the introduction of potentially invasive plants before they are released for use. This solution is especially appropriate, because the majority of non-native plants arrive in new locations due to deliberate human introduction (Mack and Erneberg 2002). If effective systems are developed to screen non-native plants for potential invasiveness, the frequency of new invaders could be significantly reduced.

Risk analysis, comprised of both risk assessment and risk management, is one strategy for screening potentially invasive plants. In this context, risk assessment scientifically quantifies the probability that a non-native plant will naturalize or invade. Risk management involves actions taken based on risk-assessment outcomes. These actions are influenced by stakeholders' values and opinions of acceptable risk and the costs and benefits of implementation (National Research Council 2009). Researchers have developed many risk-assessment models to screen non-native plants for invasiveness (Reichard and Hamilton 1997; Pheloung et al.1999; Widrlechner et al. 2004; Daehler et al. 2004; Gordon and Gantz 2008; Gassó et al. 2010). None of these models is perfect; they are subject both to false positive and false negative errors. False positives have been referred to as horticulturally limiting errors, as they represent opportunity costs to horticultural production caused by the rejection of valuable plants that are not likely to become invasive (Widrlechner et al. 2004). False negatives have been referred to as biologically significant errors, as they represent the likely introduction of a new invasive plant, creating ecosystem costs and new challenges for natural resource managers and conservationists (Widrlechner et al. 2004). Risk-assessment models may also fail to classify a plant or require information that is difficult to find in the scientific literature (Jefferson et al. 2004; Parker et al. 2007; Fox and Gordon 2009). Although risk-assessment models have limitations, they show promise for reducing introductions of new invasive plants, and some are already in use in Australia (Weber et al. 2008) and the United States (Jefferson et al. 2004).

A recent reassessment of risk-analysis methodologies (National Research Council 2009) emphasized the importance of stakeholder participation during all stages of risk analysis to increase its credibility and transparency. This aspect of risk analysis for invasive plants has received less attention than has risk-assessment model development. Some surveys have been conducted on attitudes towards invasive plants (e.g. Colton and Alpert 1998; Bardsley and Edwards-Jones 2006; Peters et al. 2006; Bremer and Park 2007; Burt et al. 2007; García-Llorente et al. 2008; Andreau et al. 2009; Daab and Flint 2010), but these efforts have not been conducted in relation to risk-assessment modeling nor to determine what stakeholders deem as acceptable risk. These previous surveys suggest there are differences of opinion on invasive plants that could present challenges for the effective application of risk-assessment models. If those concerned about the impacts of invasive plants expect risk-assessment models to be adopted and accepted, stakeholder groups should not be viewed as passive recipients of the results, especially if their opinions differ. Our primary objective was to understand stakeholder perspectives on invasive plants, their management, and risk assessment to inform model development and communication during the risk-analysis process in Iowa.

In addition to evaluating stakeholder perspectives, understanding their biases can help explain stakeholder responses. Underlying mental constructs can inform an individual's attitudes. For environmental issues, researchers have proposed that a person's sense of relatedness with nature plays a role in shaping attitudes. Ecopsychologists suggest that our failure to address environmental problems is partly due to our failure to acknowledge the ecological context of human existence (Roszak 1992; Winter and Kroger 2004). A mental construct that disassociates humans from nature may be linked to environmentally destructive behavior (Worthy 2008). For example, Neoclassical economic theory has been criticized for an anthropocentric slant that neglects adequate consideration of negative externalities that damage natural ecosystems (Hall et al. 2000; Magness 2003). We suggest that individuals holding a strong sense of connection to (and dependence on) nature in an ecological context would find it more difficult to dismiss the costs of plant invasions simply as a negative externality.

Several scales have been designed to examine individual attitudes towards nature. The New Environmental Paradigm (NEP) (Dunlap et al. 2000) has been widely used to measure pro-environmental orientation. Schultz (2000, 2001) created another scale to classify individuals' concern for the environment as egoistic, social-altruistic, or biospheric. Neither of these scales directly taps a person's sense of relatedness to (or connection with) nature, which is the mental construct we wished to evaluate. Two more recently developed scales do assess the construct we were interested in: Mayer and Frantz's (2004) Connectedness to Nature (CNS) scale and Nisbet et al.'s (2009) Nature Relatedness (NR) scale. We chose to use the NR scale because it included a metric specific for physical relatedness to nature (the NR-experience subscale).

We identified four key stakeholder groups who would be affected by risk analysis for non-native plants. First, conservation professionals often advocate rigorous management of invasive plants as part of their vocational responsibility to preserve natural areas and native biodiversity. Second, gardeners could be affected by decisions made from risk-assessment models that limit the selection of plants available for sale. Third, professional horticulturists invest significantly in the development and introduction of both native and non-native plants and, as a group, are a significant source of naturalizing plants and invaders (Reichard and White 2001). Finally, woodland landowners, some of whom engage in timber production, must deal with the negative consequences of invasive species on their land.

We surveyed representatives of these four stakeholder groups to address four main objectives: (1) assessing stakeholder awareness of invasive plants, their perception of invasive plants, and their support for general management approaches; (2) determining stakeholder perspectives on risk-assessment models as a management tool for invasive plants, and the maximum acceptable error rates for these models; (3) evaluating relationships between a stakeholder's degree of nature relatedness and attitudes towards invasive plants and their management; and (4) considering differences in opinions among stakeholder groups as they might influence the risk-analysis process. We expected conservation professionals and woodland landowners to be more concerned about invasive plants, to favor laws and mandates as a management approach, and to be less concerned about horticulturally limiting errors than about biologically significant errors. We expected professional horticulturists and gardeners to express relatively less concern about invasive plants and a greater acceptance of voluntary regulation as a management approach, and to give more consideration to horticulturally limiting errors than biologically significant errors.

Materials and Methods

We developed an online survey instrument to assess and compare the perspectives of the stakeholder groups in Iowa (conservation professionals, master gardeners, professional horticulturists, and woodland landowners). We obtained e-mail addresses for representatives of each of these groups. Conservation professionals included Iowa Department of Natural Resources employees, County Conservation Board personnel from Iowa's 99 counties, and employees of Iowa-based non-profit conservation organizations (including the Iowa Natural Heritage Foundation, Trees Forever, and the Nature Conservancy's Iowa Office) (n = 281). These were obtained from the State of Iowa employee directory, the Iowa County Conservation Board e-mail list, and employee directories from these non-profit organizations, respectively. E-mail addresses for master gardeners in Iowa (n = 405) were provided by the Iowa State University Extension Master Gardener program. Professional horticulturists were represented by members of the Iowa Nursery and Landscape Association (INLA), whose e-mail list was provided by the INLA (n = 182). A list of e-mail addresses for woodland landowners who are members of the Iowa Woodland Owners Association was provided by Iowa State University Extension Forestry (n = 137).

Survey development and administration. The four survey instruments contained questions on knowledge and familiarity with invasive plants, attitudes towards invasive plants and their management (including risk-assessment models), and a scale to measure the nature relatedness (NR) of stakeholders. The number of questions on a survey ranged from 57 to 61, with certain questions unique to each stakeholder group. Respondents were first asked to select their affiliation with a primary and secondary (if applicable) stakeholder group, to confirm their placement in the four groups. Following this, respondents were asked 21 Likert scale questions (1 "strongly disagree" to 5 "strongly agree") to evaluate their NR, including its three subscales: NR-Self (internalized identification with nature), NR-Perspective (external sense of human impacts on nature), and NR-Experience (physical familiarity with and enjoyment of nature). These questions were taken from Nisbet et al. (2009) with minor modifications. Respondents were then asked to rate priorities for various environmental issues in Iowa on a Likert scale (1 "lowest priority" to 5 "highest priority"). We asked respondents whether they had heard of invasive plants before. If they had heard of invasive plants, they were then asked what information sources they had used to learn about them. To evaluate their understanding of invasive plants, we asked respondents to provide their own definition of invasive plants. We scored responses on a pass-fail basis: if they mentioned that invasive plants are aggressive (e.g. fast growth/spread), disruptive (e.g. outcompeting natives), or a challenge to eradicate (e.g. few natural enemies, resilient), they were given a "pass." Responses that only defined invasive plants as broadly undesirable or non-native were considered insufficient. A set of four additional questions to assess general attitudes about invasive plants was evaluated on a Likert scale (1 "strongly disagree" to 5 "strongly agree").

We then supplied a common definition of invasive plants before presenting questions on invasive-plant management. These questions also used a rising 1 to 5 Likert scale unless otherwise noted. We posed three questions on general management approaches inspired by Burt et al.'s (2007) study on the potential efficacy of voluntary initiatives to regulate invasive plants. Two questions were constructed for correlation with the NR scale; this pair contrasted an ecocentric management philosophy with an anthropocentric management philosophy for invasive plants. Respondents were asked four questions about risk assessment as a management tool for invasive plants, following a basic explanation of risk assessment and its possible outcomes. We also explained error rates and then asked two open-ended questions about the maximum levels of horticulturally limiting error and biologically significant error that respondents would find acceptable in risk-assessment models.

In addition to questions common to all four stakeholder groups, 19 questions were framed specifically for single groups. Most of these were developed based on important additional considerations specific to their respective stakeholder groups. For example, given the challenge of managing invasive plants, we were curious if conservation professionals felt pessimistic about the prospect of winning battles against them. We also adapted items from an earlier survey (Peters et al. 2006) of the Minnesota horticultural industry for our professional horticulturist group.

All four surveys were reviewed by the Office for Responsible Research at Iowa State University prior to administration with SurveyMonkey™ (SurveyMonkey LLC, 2011). Unique survey links were sent to the respective stakeholder group lists via an e-mail cover letter in October 2010. We sent out a reminder to all groups after two weeks, and, due to lower initial response rate for professional horticulturists, we e-mailed a third reminder to this group. We closed the surveys in December 2010.

Survey-data editing and statistical analysis. Returned surveys that were more than 50% complete were included in data analysis. Respondents who did not report a primary or secondary group affiliation associated with the administered stakeholder e-mail list were excluded, as were duplicate respondents. If respondents skipped any NR scale items, missing values were imputed by the hot deck method (Ford, 1983). We determined descriptive statistics for all survey data by using a combination of Excel® (Microsoft Corporation, 2007) and JMP® 8 (SAS Institute Inc., 2009). Other statistical procedures (one-way ANOVA, means comparisons using Tukey's HSD, t-tests, sign-ranked matched pairs, correlations, and calculations of Cronbach's α) were conducted using JMP® 8.

Results

Response rates, demographics, interest in plants. Our online surveys were e-mailed to 1005 individuals representing the four stakeholder groups. The surveys received 471 responses, for an overall response rate of 46.9% (Table 1). The proportion of men to women was close to even overall, but disproportionately allocated among stakeholder groups; women predominated among master gardeners and men among the other three groups (Table

2). Stakeholder respondents were primarily middle-aged, well-educated, middle to upper-middle class, and long-time residents of Iowa (Table 2).

When asked to select their primary three interests in plants, the top three overall selections were gardening/landscaping at home (66.2%), visiting natural areas with plants (52.6%) and cultivating plants for food (44.6%). The top selection varied by stakeholder groups: conservation professionals selected visiting natural areas with plants (83.9%); master gardeners selected gardening/landscaping at home (92.8%); professional horticulturists selected gardening/landscaping as a profession (91.7%); and woodland landowners selected visiting natural areas with plants (62.1%).

Awareness and knowledge of invasive plants. Respondents are aware of and typically understand the concept of invasive plants. More than half the respondents in each group self-assessed their general knowledge of plants as "good" or "excellent." Professional horticulturists rated their knowledge highest, with 49.2% reporting "excellent" and 49.2% reporting "good." Nearly all respondents had heard of the term "invasive plant" before; only one respondent in the master gardener group marked "unsure." The most common sources of information about invasive plants included newspapers, magazines, or books (82.3%), educators or workshops/lectures (81.7%), conservation professionals (74.8%), colleagues (63.8%) and the Internet (60.8%). The least commonly reported information source was plant retailers or nurseries (28.4%).

We used an open-ended question asking for a definition of "invasive plant" to evaluate respondents' understanding of the concept. The proportions of respondents who met our criteria for understanding in each group were: 80.0% of conservation professionals, 96.5% of master gardeners, 92.6% of professional horticulturists, and 86.4% of woodland landowners. A notable number of conservation professionals simply defined "invasive plant" as any non-native plant (11.5%) and were the most likely to stipulate that an invasive plant is non-native (76.0%) of the stakeholder groups. Only 36.0% of master gardeners and 38.9% of professional horticulturists made the distinction that invasive plants are non-native; woodland landowners did so 58.3% of the time. Some respondents, particularly conservation professionals, indicated the possibility of an invasive plant being native (16.0% for conservation professionals, 6.9% or less for the other groups).

Perspectives on invasive plants. Respondents believe invasive plants are a problem. Although not the highest priority relative to other environmental issues in Iowa (water quality, preserving natural areas, sustainable energy, solid waste, and soil erosion all rated more highly), 69.9% of respondents considered invasive species to be a high or highest priority. When asked to respond to "I don't see invasive plants as a problem," a strong majority in each stakeholder group disagreed or strongly disagreed (Table 3). A majority of stakeholders also indicated that invasive plants are not simply weeds (73.4% of all respondents), or plants growing where they are not wanted (73.2% of all respondents) (Table 3). Though stakeholders see invasive plants as a problem, slightly over half of all respondents agreed or strongly agreed that "invasive plants aren't necessarily bad plants" (Table 3). Conservation professionals and woodland landowners did not have strong opinions on this question, as their mean responses did not differ from "unsure" ($p > 0.23$ and $p > 0.11$, respectively).

When asked to respond to the statement "I am concerned that we have used invasive plants for management projects," conservation professionals agreed or strongly agreed (79.3%, Table 6). Parallel, but not identical questions were asked of the other stakeholder groups. Only 31.7% of master gardeners agreed or strongly agreed that they were concerned they may have used invasive plants in their gardening (Table 6). Most professional horticulturists (56.6%) were concerned that they may have sold or cultivated invasive plants, and woodland landowners were very concerned (89.1%) about the impact of invasive plants on their property (Table 6).

Perspectives on invasive plant management. Respondents believe we have a responsibility to manage invasive plants and support the use of state laws or mandates for this purpose. A strong majority (92.9%) of respondents disagreed or strongly disagreed with a "hands off" approach to managing invasive plants or letting nature take its course (Table 4). Stakeholders also disagreed or strongly disagreed (87.4%) that "we should only manage invasive plants if they cause trouble for people" and instead favored taking responsibility to protect our natural areas from invasive plants (88.5% agree or strongly agree, Table 4). Voluntary management was not deemed sufficient by stakeholders, with 59.6% disagreeing or strongly disagreeing that "invasive plants should be managed on a voluntary basis" (Table

4). Instead they favored state laws or mandates, with 60.9% agreeing or strongly agreeing with this, although 26.3% were unsure (Table 4).

Attitudes towards risk assessment. Respondents supported implementation of risk-assessment models as a management tool for invasive plants, but expressed concerns about the accuracy and effectiveness of such models. A majority (78.7%) agreed or strongly agreed that risk assessment has the potential to prevent future plant invasions (Table 5). When asked how much they agreed or disagreed with the statement "I don't think we should use risk assessment," most (74.3%) disagreed or strongly disagreed (Table 5). Although in agreement about the potential benefits of risk assessment, respondents were divided on its effectiveness. Conservation professionals and professional horticulturists exhibited more skepticism about the effectiveness of risk assessment than did master gardeners, whereas woodland landowners were evenly divided (Table 5). A majority of conservation professionals (63.8%) and professional horticulturists (61.4%) also expressed concern about the accuracy of risk assessment. In contrast, master gardeners and woodland landowners were of mixed opinions (Table 5).

Slightly more than one-half of conservation professionals expressed willingness to use results from risk assessment to guide land-management decisions (Table 6). When professional horticulturists were asked a similar question, a majority agreed or strongly agreed that they would be willing to use risk assessment in their businesses decisions (Table 6). Most professional horticulturists also expressed a willingness to conduct field trials on plants classified as "further analysis" by the models (Table 6). If a risk-assessment model rejected a plant, professional horticulturists agreed or strongly agreed that they would discontinue sale of that plant (Table 6). Not surprisingly, a slightly smaller percentage would do so if the plant had a high profit margin (Table 6). Master gardeners indicated that they would rather buy plants from a retailer who used risk assessment, and most would be willing to pay more for such plants (Table 6).

Acceptable error rates for risk-assessment models. We asked our stakeholders an open-ended question about the maximum error rates they would be willing to accept for both biologically significant and horticulturally limiting errors. Based on median values, respondents believed that biologically significant errors (which would allow the use of non-native plants that might become invasive) in risk-assessment models should not exceed 5 to 10% (Figure 1). Conservation professionals were the least likely to accept high biologically significant error rates, and master gardeners were the most likely to. Median values revealed a somewhat greater acceptance for horticulturally limiting errors (which would prohibit the use of non-native plants that were unlikely to become invasive) among respondents, who found error rates between 10 and 20% to be acceptable (Figure 1). Analysis of matched pairs for each error type offered further support of stakeholders' greater acceptance of horticulturally limiting errors than of biologically significant errors ($P < 0.001$). Mean differences between individual responses on these two items ranged from 4.3% for professional horticulturists to 18.7% for conservation professionals.

Nature relatedness scores and relationships to invasive plant perspectives. Overall, nature relatedness (NR) scores for all stakeholder groups were high ($\bar{x} = 4.0$) and not different from each other; only the NR-Experience subscale differed among groups (Table 7). Variance of NR scores was relatively low (0.41), with a narrow range of scores (2.9 to 5.0). Cronbach's α showed high inter-item consistency for overall NR score (range 0.82 to 0.85) and the subscales; although the low α for NR-Experience among professional horticulturists was an exception (Table 7).

Despite the relative uniformity of NR scores, correlation of overall NR scores to other survey questions differed in strength and significance among stakeholder groups. Correlations were weaker and generally less significant for woodland landowners than they were for the other three groups (Table 8). "In general, I don't see invasive plants as a problem" had moderate negative correlations to NR for both conservation professionals and professional horticulturists (Table 8). A hands-off approach to management was also negatively correlated with NR, most strongly for conservation professionals and master gardeners (Table 8). "I don't think we should use risk assessment" was negatively correlated with NR (Table 8). Acceptable error rates of both types were not correlated with NR except for master gardeners, where negative correlations were observed for both biologically significant and horticulturally limiting errors (Table 8). Managing plants only when they cause trouble for people was negatively correlated with NR scores; conversely, belief in responsibility to protect natural areas from invasive plants was positively and significantly correlated with NR for all stakeholder groups (Table 8). Positive correlations with NR for passing state laws and mandates to manage invasive plants were also significant across all stakeholder groups and mirrored by negative correlations to managing plants on a voluntary basis (Table 8).

Correlations of NR subscales to these questions, while not presented here (see Appendix D), followed the same directions of the correlations based on overall NR score. Correlations to subscales were weaker than for the overall NR score for both professional conservationists and master gardeners. In contrast, in three instances (questions 2, 3, and 6 in Table 8), professional horticulturists showed stronger correlations (in the -0.43 to -0.50 range) with NR-Perspective than with the NR score overall. Woodland landowners, whose correlations were weak and non-significant with NR score overall, drew more strongly from NR-Experience in five cases (questions 1, 2, 3, 4, and 7 in Table 8). The first three questions were significant when correlated to NR-Experience (strength -0.27 to -0.30) even though corresponding correlations with NR score overall were not.

Discussion

Our respondents have a good understanding of invasive plants and believe they are a problem. They also believe that we have a responsibility to manage invasive plants, both for human and nonhuman well-being. Respondents support use of risk-assessment models as a management approach for invasive plants, but have concerns about model accuracy. In particular, they show greater concern about biologically significant errors than horticulturally limiting errors. Nature relatedness shapes individual perspectives on invasive plants as well. Overall, differences between groups were not as pronounced as we expected, indicating an opportunity for cooperation among these groups during risk analysis for invasive plants.

Stakeholder perspectives on invasive plants and their management. Colton and Alpert (1998) concluded that public awareness and understanding of biological invasions by plants was poor, and Steele et al. (2006) found that only 34% of West Virginia woodland landowner respondents had heard or read information about invasive plants. However, Daab and Flint (2010) reported 88% of the general public in Colorado had heard or read about invasive plants. Given this wide range of awareness, we were unsure what to expect with our respondents. Fortunately, our respondents in Iowa were very aware of the term "invasive plant," and the majority also demonstrated comprehension of its meaning with their write-in answers. They rarely indicated some misconceptions about invasive plants, such as perceiving them to be the same thing as weeds (Table 3). The higher level of understanding and awareness among our stakeholder groups provides a stronger foundation for both informed opinions and discussion on the issue of invasive plants for risk analysis.

Respondents are in agreement that invasive plants are a problem. Our results resembled those of Daab and Flint's (2010) study of the general public in Colorado, who also agreed that invasive plants were a concern. Our stakeholder groups differed somewhat in how strongly they perceived invasive plants to be a problem. Nearly all conservation professionals disagreed or strongly disagreed with the statement "in general, I don't see invasive plants as a problem," but fewer master gardeners and professional horticulturists took this position (Table 3). Given that conservation professionals are more likely to wrestle with the negative consequences of invasive plants through their vocation, the differences between these groups are not surprising.

Other intriguing differences arose when concern about invasive plants was framed in a more group-specific manner (questions 1, 5, 8, 14, and 16 in Table 6). Both conservation professionals and woodland landowners confirmed their strong concern with these targeted questions, but this concordance was not observed for professional horticulturists or master gardeners (Table 6). For professional horticulturists, this may be in part because they feel confident they are already taking steps to minimize use of invasive plants. This is supported by Peters et al.'s (2006) study of professional horticulturists, where 89% of respondents preferred to direct customers to plants that were least likely to harm the environment. Most (78.3%) of our professional horticulturist respondents also did not believe that introducing new plants is more important than worrying about whether or not they are invasive (Table 6). Master gardeners may believe that plant suppliers are taking primary responsibility by not offering invasive plant selections, reducing concerns that they may have used invasive plants in their gardening. Alternatively, they may feel that since their own property is small, they can effectively remove any invasive plants or weeds they find and, thus, do not contribute significantly to the problem.

While there is a tendency to think of invasive plants as "bad" from a conservation standpoint, other stakeholders may value their benefits. Colton and Alpert (1998) observed that a majority of respondents had something good to say about them. Similarly, our respondents do not necessarily equate invasive plants with "bad" plants (Table 3). In a study by Bardsley and Edwards-Jones (2006) in the Mediterranean, non-ecologists ranked the positive impacts of invasive plants more highly and recognized more of their benefits (relative to ecologists). The differences in our stakeholder groups parallel this, with conservation professionals being more likely to equate invasive plant with "bad" than do master gardeners and professional horticulturists (Table 3). When working with horticulturists and gardening groups during risk management, it may be worthwhile to consider options that allow benefits from potentially invasive plant species while still minimizing their risks. One possibility is to develop sterile cultivars of known invasive plants (Ranney 2006), an option that might be agreeable to invasive-savvy plant consumers (e.g. Kelley et al. 2006).

For management approaches, we did not find the differences in perspectives among stakeholder groups that we expected. Most respondents across groups believed that some action should be taken to manage invasive plants, and had a preference for state laws and mandates over voluntary programs (Table 4). Previous work by Peters et al. (2006) found that 43% of Minnesota Nursery and Landscape Association respondents preferred government regulation for invasive plants while 43.1% desired private or industry self-regulation (which resembles, but is not synonymous with voluntary management). Kelley et al. (2006) found Pennsylvania gardeners similarly non-receptive to government regulation (only 41.3% supported it). Thus, we expected professional horticulturists and gardeners to favor voluntary regulation over state laws and mandates, but this was not the case for our respondents. There were no differences between groups on voluntary regulation, which was supported less than was the concept of state regulation by all stakeholder groups (Table 4). Given that professional horticulturists often have a personal economic stake in plant introductions, it is a good sign for future negotiations in the risk-analysis process that this group is more amenable to a regulatory approach than previous studies have suggested. Overall, stakeholders are receptive to the concept of using state laws and mandates to manage invasive plants, but enough of them are uncertain (26.3%) or in disagreement (12.8% disagreed or strongly disagreed) that it is important to engage them in dialogue about this aspect. While doing so, common points of agreement about management may be used to advance implementation of risk-assessment models. More specifically, since respondents strongly believe we have a responsibility to manage invasive plants both for human and non-human well-being (Table 4), this could then be emphasized as a central objective with relatively little objection.

Stakeholder perspectives on risk-assessment models and error rates. Conservation professionals were more skeptical about the effectiveness of risk assessment than were other groups. Nearly two-thirds expressed concern about the accuracy of risk assessment. Since conservation professionals reported a much lower tolerance for biologically significant errors than for horticulturally limiting errors ($P < 0.0001$), allowing few or no invaders to pass by screening will be a critical element in obtaining support from this group. Master gardener respondents were the most optimistic group, but were still uncertain about the accuracy of risk-assessment models. Their mean response to "I am concerned about the accuracy of risk assessment" did not differ from "unsure" ($P = 0.66$), suggesting that master gardeners may not have enough information about risk-assessment models to have formed strong opinions. During risk analysis, more details about risk-assessment models and their strengths and weaknesses should be communicated to master gardeners. Professional horticulturist respondents hold views that are intermediate between those of conservation professionals and master gardeners. Professional horticulturists did not differ in their acceptance of biologically significant and horticulturally limiting errors ($P = 0.38$). To meet the needs of this group of stakeholders, addressing horticulturally limiting errors will be as important as addressing biologically significant errors.

Some researchers have expressed concerns that risk-assessment models must have high classification rates (few "further analysis" results) because field trials are expensive and time-consuming for the nursery industry (White and Schwartz 1998). It is encouraging to see that a majority (57.2%) of professional horticulturists expressed willingness to conduct field trials on plants classified as "further analysis" by risk-assessment models (Table 6). Still, nearly one-fourth would be unwilling to do this, and we do not know the extent to which those who are willing could actually conduct meaningful long-term trials. Researchers developing risk-assessment models should still strive for good classification rates in light of this information.

It is also important to know if horticulturists would follow the suggested outcomes of risk-assessment models in terms of limiting sale of a potentially invasive plant. In the survey by Peters et al. (2006), 69% of Minnesota respondents agreed or strongly agreed that they would not sell a plant if they knew it had the potential to become invasive; 60.7% of our respondents did the same for a similar question, with slightly fewer agreeing if the plant had a high profit margin (Table 6). While this is a good start, because the implementation of risk-assessment models depends on the cooperation of nurseries who propagate and sell plants, we would like to see this value much higher to ensure effective regulation. If nurseries are hesitant to follow the results of risk-assessment, they may be encouraged to do so by master gardener respondents reporting that they would rather buy plants from a retailer who used risk assessment (Table 6). Many master gardeners also indicated they would be willing to pay more for plants that had gone through such screening, a finding similar to that of Kelley et al. (2006) among their "invasive-savvy" gardeners. However, it has been noted that although respondents indicate willingness to pay in surveys, their actual behavior may differ (Diamond and Hausman 1994).

Stakeholder opinions on error rates are of particular importance to researchers when developing risk-assessment models. Scientists typically set their own goals for model accuracy, but those of other stakeholders have been unknown. A meta-analysis of risk-assessment models including and derived from the Australian Weed Risk Assessment (WRA) bore false negative rates (analogous to biologically significant error rates) of 0 to 12.7% and false positives (analogous to horticulturally limiting error rates) of 1.9 to 10.5% (Gordon et al. 2008). A study by Jefferson et al. (2004) in the Chicago region for the Australian WRA yielded biologically significant error rates of 0 to 17.5% and horticulturally limiting error rates of 2.5 to 35.5%. Other, regional models for woody invasive plants (which include systems derived from Reichard and Hamilton's (1997) decision tree), range from 2.5% to 9.7% for biologically significant error rates and 3.7% to 23.7% for horticulturally limiting error rates (Widrlechner et al. 2004; Widrlechner et al. 2009).

Based on median values, our results show that a typical stakeholder would accept biologically significant error rates of 5 to 10% and horticulturally limiting error rates of 10 to 20% (Figure 1). Risk-assessment models currently available often meet those targets, as models have been designed to generate fewer biologically significant errors at the expense of increased horticulturally limiting errors. This tradeoff appears to be acceptable to many of our respondents, because individuals within all stakeholder groups usually reported higher acceptable values for horticulturally limiting errors than for biologically significant errors. Because risk analysis is a cooperative process, the needs of all key stakeholder groups should be considered when determining acceptable levels of risk in error rates. Fortunately, there were fewer differences than expected in acceptable error rates among our stakeholder groups. Although mean biologically significant error rates did fall in the pattern we anticipated (conservation professionals and woodland landowners reported lower mean values), only master gardeners and conservation professionals differed from one another. Responses on horticulturally limiting error rates were not statistically different from each other. In some cases, lack of significance may be due to outliers, or error rates greater than 50% (probabilistically analogous to or worse than flipping a coin). Some outliers are due to respondents who likely misunderstood the question, but others may reflect respondents who are truly unconcerned about high error rates.

Relationships between nature relatedness and perspectives on invasive plants. Stakeholder groups did not differ in nature relatedness (NR) except for the NR-Experience subscale. It makes sense that conservation professionals rated most highly on this subscale (followed by woodland landowners), as NR-Experience expresses a person's physical familiarity and desire to interact with nature (Nisbet et al. 2009). Conservation professionals interact with nature for their living, and those who are woodland landowners also manage their own private lands. Master gardeners displayed lower NR-Experience scores, possibly reflecting that, although they desire to experience nature, they do so in a recreational rather than a vocational context (Table 7).

The relatively narrow range of NR scores was unexpected, but reveals an important characteristic about these stakeholder groups. Part of Nisbet et al.'s (2009) original study involved surveying federal and private executives in Canada. Their NR scores ranged from

2.1 to 4.9 with a median of 3.7 (n = 145). Our range of scores ran from 2.9 to 5.0 with an overall median of 4.1 (n = 471). This suggests that each stakeholder group represents relatively homogenous populations that are more connected to nature than might be found in other groups. If high NR scores are successfully linked to pro-environmental behaviors as Nisbet et al. (2009) suggested, strong correlations should be present across all these stakeholder groups between NR scores and perspectives on invasive plants.

We did see evidence of these correlations, and the directions they follow make intuitive sense. Where Nisbet et al. (2009) correlated NR scores to broader perspectives on the environment, such as membership in environmental organizations or self-identification as environmentalists, our correlations show that NR as a mental construct may also play a role in shaping environmental attitudes on specific issues. For example, we tailored a pair of questions specifically for comparison with NR scores: “we should only manage plants if they cause trouble for people” and “we have a responsibility to protect our natural areas from invasive plants.” We expected and found that the first item was negatively correlated with NR score, and the second, more ecocentric statement, was positively correlated with NR score (Table 8).

Although the directions of correlations were as expected, their strength and significance varied across stakeholder groups. Woodland landowner responses showed noticeably weaker correlations than did the other three groups, suggesting that their concern about invasive plants and their perspectives on management may be influenced more by other mental constructs or experiences. Given that correlations to NR-Experience were more significant for this group, woodland landowner’s physical relatedness to nature may be more important than other aspects of the NR score. The other stakeholders’ perspectives were better explained by their overall NR scores. Conservation professionals and professional horticulturists showed closer links between NR scores and perspectives on invasive plants. For these two groups, their livelihoods involve working with nature, which may account for closer connections. Those with a stronger sense of nature relatedness may also be inherently drawn to such professions.

Implications for management. Stakeholder attitudes can shape what types of management are acceptable and affect management success. In the worst of cases, conflicting interests can create delays that result in failed control efforts, as occurred with a grey squirrel eradication project in Italy (Genovesi and Bertolino 2001). Management of invasive plants may be controversial, particularly if pre-emptive measures such as risk-assessment models are applied. Models that allow no new invasive plants into an area often also exclude non-native plants that would have been innocuous; this creates a potential conflict between those who want to prevent new invaders from establishing (i.e. conservation professionals and woodland landowners) and those whose livelihoods or recreational activities focus on plant introduction (i.e. professional horticulturists and gardeners). However, responses from these different stakeholder groups reveal that conflicts of perspective regarding the implementation of risk-assessment models are not severe. Respondents are united by a sense of relatedness to nature and have a responsible outlook on managing invasive plants. Their support of both risk-assessment models and the use of state laws to manage invasive plants suggest many would also be receptive to routine screening of non-native plants for invasiveness. Challenging work on the further details of effective policies remains, which will require additional refinement of risk-assessment models and further education of stakeholders. With a majority of stakeholders in agreement on the problem and possible solutions, preventive management efforts for invasive plants are likely to be more successful than they might be otherwise.

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Table 1. Response rates for online surveys about invasive plants e-mailed to four stakeholder groups in Iowa.

Stakeholder group	Surveys administered (n)	Total respondents (n)	Response rate (%)
Conservation professionals	281	130	46.3
Master gardeners	405	207	51.1
Professional horticulturists	182	60	33.0
Woodland landowners	137	74	54.0

Table 2. Demographics of four stakeholder groups from surveys on invasive plants in Iowa.

Stakeholder group	Male / female (n)	Median age (yr)	Average Iowa residence time (yr)	Education		Annual income		
				Associate's degree or less (%)	Bachelor's degree or more (%)	$49,999 or less (%)	$50,000 to $99,999 (%)	$100,000 or more (%)
Conservation professionals	94 / 32	44	39	6.3	93.7	11.3	62.1	17.7
Master gardeners	42 / 154	60	49	39.1	59.9	17.7	35.4	16.7
Professional horticulturists	36 / 21	49	48	35.1	63.2	20.0	38.2	27.3
Woodland landowners	56 / 12	60	58	26.8	73.2	12.9	41.4	28.6

Table 3. Stakeholder responses to survey questions on invasive plants. Means and standard deviations (in parentheses following each mean) represent numerical coding of a five-point Likert scale: strongly disagree (1), disagree (2), unsure (3), agree (4), and strongly agree (5).

		Five-point Likert scale (%)				
Survey question and group	Mean (SD) [z]	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
1. Invasive plants are the same thing as weeds.						
Conservation professionals (n = 130)	2.3 (1.0)	13.1	64.6	3.8	13.8	4.6
Master gardeners (n = 206)	2.3 (1.0)	16.0	57.8	7.8	14.1	4.4
Professional horticulturists (n = 60)	2.5 (1.2)	18.3	45.0	8.3	23.3	5.0
Woodland landowners (n = 74)	2.3 (1.1)	21.6	51.4	8.1	13.5	5.4
2. If it grows where I don't want it, it is an invasive plant to me.						
Conservation professionals (n = 130)	2.0 (0.8) a	20.0	66.9	3.1	8.5	1.5
Master gardeners (n = 206)	2.5 (1.2) b	17.0	47.6	7.8	20.9	6.8
Professional horticulturists (n = 60)	2.2 (1.0) ab	23.3	55.0	5.0	15.0	1.7
Woodland landowners (n = 73)	2.4 (1.1) ab	19.2	49.3	8.2	19.2	4.1
3. Invasive plants aren't necessarily bad plants.						
Conservation professionals (n = 130)	2.9 (1.2) a	13.1	32.3	10.8	41.5	2.3
Master gardeners (n = 203)	3.4 (1.1) b	9.4	15.3	12.8	55.7	6.9
Professional horticulturists (n = 60)	3.4 (1.0) b	3.3	21.7	11.7	55.0	8.3
Woodland landowners (n = 74)	3.2 (1.2) ab	10.8	18.9	14.9	48.6	6.8
4. In general, I don't see invasive plants as a problem.						
Conservation professionals (n = 130)	1.5 (0.6) a	59.2	37.7	1.5	0.8	0.8
Master gardeners (n = 204)	1.9 (0.9) b	35.3	49.0	8.8	6.4	0.5
Professional horticulturists (n = 60)	2.1 (1.0) b	30.0	45.0	11.7	11.3	0.0
Woodland landowners (n = 74)	1.7 (1.0) ab	50.0	37.8	6.8	1.4	4.1

[z] Means followed by the same letter within a column for each question are not different at $P \leq 0.05$ according to Tukey's HSD. Means are not different unless noted.

Table 4. Stakeholder responses to survey questions on invasive plant management. Means and standard deviations (in parentheses following each mean) represent numerical coding of a five-point Likert scale: strongly disagree (1), disagree (2), unsure (3), agree (4), and strongly agree (5).

Survey question and group	Mean (SD) [z]	Five-point Likert scale (%)				
		Strongly disagree	Disagree	Unsure	Agree	Strongly agree
1. If a plant is invasive we should just let nature take its course and not interfere.						
Conservation professionals (n = 130)	1.5 (0.6) a	57.7	37.7	3.1	1.5	0.0
Master gardeners (n = 205)	1.6 (0.7) a	52.7	40.5	5.4	1.0	0.5
Professional horticulturists (n = 60)	2.0 (0.7) b	20.0	68.3	8.3	1.7	1.7
Woodland landowners (n = 73)	1.6 (0.7) a	52.1	39.7	6.8	0.0	1.4
2. We should only manage invasive plants if they cause trouble for people.						
Conservation professionals (n = 130)	1.6 (0.8) a	50.0	14.5	3.1	4.6	0.8
Master gardeners (n = 205)	1.8 (0.9) a	40.5	47.3	5.9	5.4	1.0
Professional horticulturists (n = 60)	2.2 (1.0) b	25.0	46.7	11.7	15.0	1.7
Woodland landowners (n = 73)	1.7 (0.7) a	43.8	47.9	5.5	2.7	0.0
3. We have a responsibility to help protect our natural areas from invasive plants.						
Conservation professionals (n = 130)	4.3 (1.0)	5.4	1.5	1.5	36.9	54.6
Master gardeners (n = 203)	4.1 (1.0)	6.9	1.5	4.9	46.1	40.7
Professional horticulturists (n = 60)	4.1 (0.8)	0.0	5.0	10.0	55.5	30.0
Woodland landowners (n = 74)	4.2 (0.9)	2.7	4.1	2.7	47.9	42.5
4. State laws or mandates should be passed to adequately manage invasive plants.						
Conservation professionals (n = 130)	3.8 (1.1) a	6.2	3.8	19.2	42.3	28.5
Master gardeners (n = 204)	3.7 (1.0) ab	3.4	7.8	29.8	38.0	21.0
Professional horticulturists (n = 60)	3.4 (1.0) b	3.3	18.3	25.0	41.7	11.7
Woodland landowners (n = 74)	3.6 (1.0) ab	1.4	13.7	30.1	37.0	17.8

[z] Means followed by the same letter within a column for each question are not different at $P \leq 0.05$ according to Tukey's HSD. Means are not different unless noted.

Table 4. (continued)

Survey question and group	Mean (SD)[z]	Five-point Likert scale (%)				
		Strongly disagree	Disagree	Unsure	Agree	Strongly agree
5. Invasive plants should be managed on a voluntary basis.						
Conservation professionals (n = 130)	2.3 (1.0)	19.4	46.5	17.8	14.0	2.3
Master gardeners (n = 204)	2.4 (1.1)	19.0	40.5	19.0	18.5	2.9
Professional horticulturists (n = 60)	2.5 (1.1)	16.7	43.3	16.7	18.3	5.0
Woodland landowners (n = 74)	2.7 (1.2)	13.9	34.7	22.2	22.2	6.9

[z] Means followed by the same letter within a column for each question are not different at $P \leq 0.05$ according to Tukey's HSD. Means are not different unless noted.

Table 5. Stakeholder responses to survey questions on risk assessment as a management tool for invasive plants. Means and standard deviations represent numerical coding of a five-point Likert scale: strongly disagree (1), disagree (2), unsure (3), agree (4), and strongly agree (5).

Survey question and group	Mean (SD)[z]	Five-point Likert scale (%)				
		Strongly disagree	Disagree	Unsure	Agree	Strongly agree
1. I think risk assessment has the potential to prevent future plant invasions.						
Conservation professionals (n = 130)	3.7 (0.8) b	0.8	10.0	16.9	65.4	6.9
Master gardeners (n = 202)	4.0 (0.7) a	0.5	3.0	13.4	61.9	21.3
Professional horticulturists (n = 57)	3.8 (0.7) ab	1.8	3.5	14.0	71.9	8.8
Woodland landowners (n = 72)	3.8 (1.0) ab	5.6	2.8	15.3	54.2	22.2
2. I don't think we should use risk assessment.						
Conservation professionals (n = 130)	2.2 (0.7) a	12.3	58.5	21.1	6.2	0.0
Master gardeners (n = 201)	2.0 (0.7) b	21.4	58.7	17.4	2.5	0.0
Professional horticulturists (n = 56)	2.2 (0.7) ab	16.1	50.0	32.1	1.8	0.0
Woodland landowners (n = 72)	2.2 (0.7) ab	22.2	48.6	23.6	1.4	4.2
3. I am skeptical about how effective risk assessment could be.						
Conservation professionals (n = 130)	3.2 (0.9) a	3.1	24.6	26.2	43.8	2.3
Master gardeners (n = 200)	2.7 (1.0) b	8.0	44.0	23.5	23.5	1.0
Professional horticulturists (n = 57)	3.1 (1.0) a	3.5	26.3	24.6	43.9	1.8
Woodland landowners (n = 72)	3.0 (1.0) ab	5.6	34.7	22.2	33.3	4.2
4. I am concerned about the accuracy of risk assessment.						
Conservation professionals (n = 130)	3.5 (0.8) a	1.5	10.8	23.8	62.3	1.5
Master gardeners (n = 197)	3.0 (1.0) b	5.6	29.9	28.4	34.0	2.0
Professional horticulturists (n = 57)	3.4 (1.0) a	5.3	14.0	19.3	54.4	7.0
Woodland landowners (n = 72)	3.2 1(.0) ab	2.8	22.2	30.6	38.9	5.6

[z] Means followed by the same letter within a column for each question are not different at $P \leq 0.05$ according to Tukey's HSD.

Table 6. Stakeholder responses to survey questions unique to each group on invasive plants and their management. Means and standard deviations represent numerical coding of a five-point Likert scale: strongly disagree (1), disagree (2), unsure (3), agree (4), and strongly agree (5).

Group and survey question	Mean (SD)	Five-point Likert scale (%)				
		Strongly disagree	Disagree	Unsure	Agree	Strongly agree
Conservation professionals						
1. I am concerned that we have used invasive plants for management projects. (n = 130)	3.9 (1.0)	2.3	12.3	6.2	56.2	23.1
2. Other conservation or land management issues should take a higher priority than invasive species. (n = 130)	2.8 (0.9)	5.4	33.8	33.1	26.2	1.5
3. Managing invasive species is fighting a losing battle. (n = 130)	2.4 (0.8)	10.0	54.6	24.6	9.2	1.5
4. I am willing to use results from risk assessment to guide land management. (n = 130)	3.5 (0.8)	0.0	11.5	33.1	46.9	8.5
Master gardeners						
5. I'm concerned that I may have used invasive plants in my gardening. (n = 205)	2.7 (1.1)	9.8	45.4	13.2	29.3	2.4
6. I would rather buy plants from a retailer who has used risk assessment. (n = 201)	4.1 (0.7)	0.0	3.5	9.0	63.2	24.4
7. I would be willing to pay more for a plant sold by a retailer who has used risk assessment. (n = 200)	3.6 (0.9)	0.5	11.0	27.0	47.0	14.5

Table 6. (continued)

Group and survey question	Mean (SD)	Five-point Likert scale (%)				
		Strongly disagree	Disagree	Unsure	Agree	Strongly agree
Professional horticulturists						
8. I am concerned that we have sold or cultivated invasive plants. (n = 60)	3.3 (1.1)	5.0	25.0	13.3	48.3	8.3
9. Introducing new and interesting plants is more important than worrying about if these plants will become invasive. (n = 60)	2.1 (0.9)	25.0	53.3	13.3	8.3	0.0
10. I am willing to use results from risk assessment in my business decisions. (n = 57)	3.8 (0.6)	0.0	1.8	22.8	68.4	7.0
11. I am willing to conduct field trials on plants classified as "further analysis." (n = 56)	3.4 (0.9)	1.8	21.4	19.6	53.6	3.6
12. If the risk assessment model rejected a plant, I would discontinue sale of it. (n = 56)	3.6 (0.9)	1.8	7.1	30.4	48.2	12.5
13. I would discontinue sale of a plant even if it had a high profit margin. (n = 55)	3.6 (0.8)	0.0	5.5	38.2	43.6	12.7
Woodland landowners						
14. I'm concerned about the impact of invasive plants on my own property. (n = 73)	4.3 (0.9)	1.4	4.1	5.5	38.4	50.7
15. It's my responsibility to deal with invasive plants on my property. (n = 72)	4.3 (0.7)	0.0	2.8	6.9	51.4	38.9
16. It would concern me if a plant was invading on property close to my own. (n = 57)	4.3 (0.5)	0.0	0.0	4.2	61.1	34.7

Table 7. Mean nature relatedness (NR) scores of four stakeholder groups from a survey on invasive plants in Iowa. NR scores are based on a five-point Likert scale. High values represent high nature relatedness and low values represent low nature relatedness. Cronbach's α follows in parentheses.

Stakeholder group	Overall NR score	Nature relatedness subscales		
		NR-Self	NR-Perspective	NR-Experience [z]
Conservation professionals (n = 130)	4.1 (0.83)	4.0 (0.75)	3.9 (0.66)	4.4 (0.64) a
Master gardeners (n = 207)	4.0 (0.84)	4.1 (0.74)	4.0 (0.69)	4.1 (0.67) b
Professional horticulturists (n = 60)	4.0 (0.82)	4.0 (0.75)	3.8 (0.70)	4.2 (0.50) bc
Woodland landowners (n = 74)	4.1 (0.85)	4.1 (0.78)	3.9 (0.68)	4.4 (0.73) ac

[z] Means followed by the same letter are not different at $P \leq 0.05$ according to Tukey's HSD.

Table 8. Correlations of overall nature relatedness (NR) scores to selected questions about attitudes regarding invasive plants and their management, by stakeholder group.

Survey Question	Overall NR score correlation (r)			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
1. In general, I don't see invasive plants as a problem.	- 0.41 ***	- 0.12	- 0.47 ***	- 0.11
2. If a plant is invasive we should just let nature take its course and not interfere.	- 0.44 ***	- 0.32 ***	- 0.29 *	- 0.17
3. We should only manage plants if they cause trouble for people.	- 0.48 ***	- 0.34 ***	- 0.34 **	- 0.18
4. We have a responsibility to protect our natural areas from invasive plants.	0.44 ***	0.26 ***	0.44 ***	0.40 ***
5. State laws or mandates should be passed to adequately manage invasive plants.	0.26 *	0.21 **	0.36 **	0.37 **
6. Invasive plants should be managed on a voluntary basis.	- 0.22 *	- 0.22 **	- 0.40 **	- 0.12
7. I don't think we should use risk assessment.	- 0.21 *	- 0.24 ***	- 0.30 *	- 0.02
Biologically significant error	- 0.02	- 0.21 **	- 0.03	-0.03
Horticulturally limiting error	0.12	- 0.26 **	0.30	0.02

* value is statistically significant at $P \leq 0.05$
** value is statistically significant at $P \leq 0.01$
*** value is statistically significant at $P \leq 0.001$

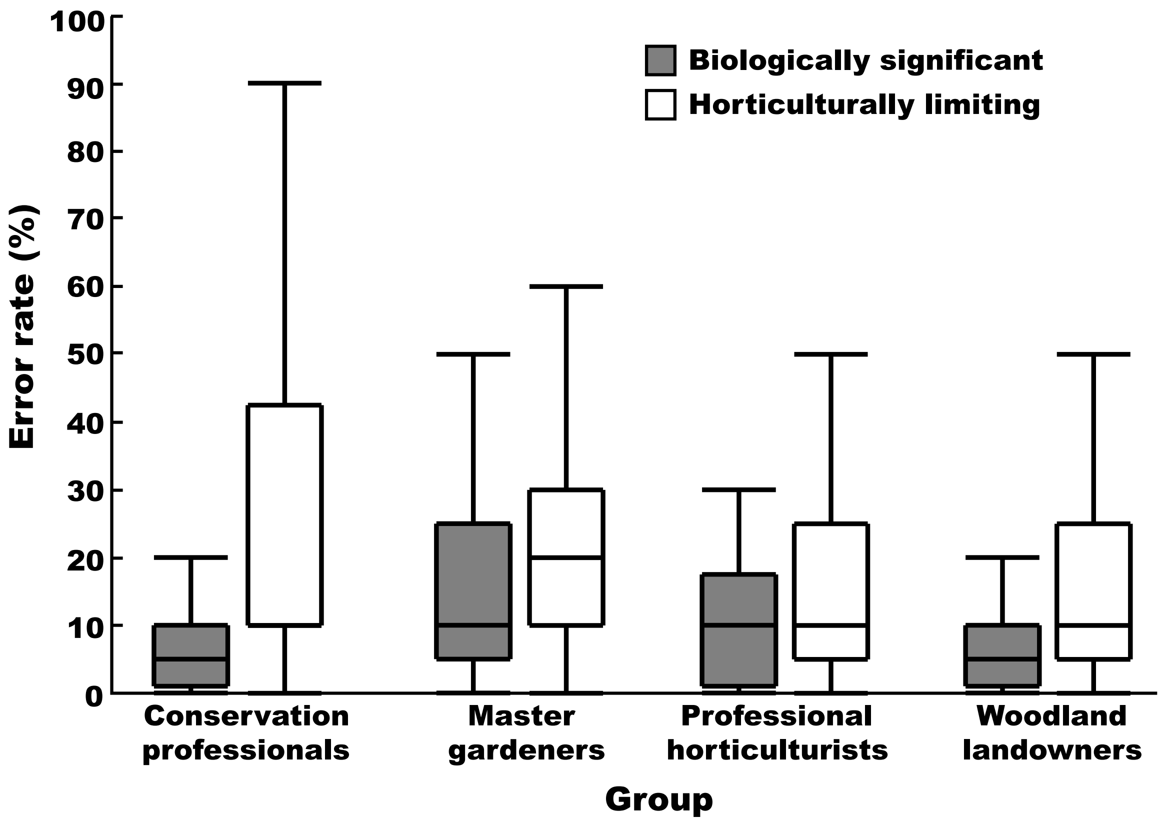

Figure 1. Box plots of maximum tolerated biologically significant error rates and horticulturally limiting error rates for risk-assessment models as reported by four stakeholder groups. Median does not appear for conservation professionals as it is the same as the 1st quartile. Whiskers extend to outermost data point that falls within 1.5 times the interquartile range. Sample sizes are as follows: land managers (n = 94), master gardeners (n = 159), professional horticulturists (n = 33), and woodland landowners (n = 55).

CHAPTER 4
GENERAL CONCLUSIONS

Risk analysis is an ongoing, iterative process and should not be viewed as one that has a clear ending point. Conditions change and new challenges come to the fore. This is particularly the case when dealing with innately complex ecological risks, such as those posed by invasive plants. This thesis represents some of the ongoing efforts to successfully manage and understand invasive plants.

In Chapter 2, we learned that researchers have more work to do in developing risk-assessment models for predicting the naturalization of non-native plants. Power and accuracy of current models did not perform as well as we would prefer when subjected to validation with a new data set. Much of this may be due to the nature of the data set used to validate the models, and it is known that classification and regression (CART) models in particular can be sensitive to small changes in data sets during training. Relative to each other, some approaches proved better than others. The CART model continued to do well in reducing horticulturally limiting errors, and the random forest approach also showed promise in improving the power and accuracy of predictions. The random forest approach is worth investigating further as we strive to develop a regional model for use in the Upper Midwest. It does have a significant drawback, however: it cannot be presented as a diagram and is more difficult for its potential users to understand. Developing easy to use risk-assessment models represents an important challenge that must be met if they are to be successfully adopted.

Engaging stakeholders on the issue of invasive plants and risk assessment is also an important element of risk analysis. In Chapter 3, we learned that a diverse set of four Iowa stakeholder groups is well informed about the issue of invasive plants and supports management efforts to control them. They also have a strong sense of their connection to nature, which may play some role in shaping the concerns these groups have regarding invasive plants and their impacts. A majority believe that state laws and regulations are the preferred method of managing invasive plants, and this may take the form of requiring implementation for risk-assessment models that screen plants for naturalization or invasion potential. As far as the outcomes of risk-assessment models, most stakeholders are more concerned about biologically significant errors than about horticulturally limiting errors. This means that emphasizing low biologically significant error rates over horticulturally limiting error rates would be preferred by most stakeholders. Researchers now have a standard they may reference (other than their own personal standards) for determining if an error rate is too high in risk-assessment models.

As an iterative process, there are still challenges in risk analysis for invasive plants that presents opportunities for future improvements. All risk-analysis models depend to some extent on information about the plants (e.g. life-history). Researchers, my colleagues and I included, have experienced difficulty obtaining this information for some species. There is no "one-stop shopping" repository for plant information, and efforts to develop risk-assessment models (and to use them) could be greatly improved by database systems that organize this information better. Such a database could be used to better document naturalization status for new non-native plants. Some efforts along these lines do already exist. The University of Connecticut is currently sponsoring IPANE (Invasive Plant Atlas of New England) with the goal of providing a comprehensive web-access database of invasive and potentially invasive plants (Merhoff et al. 2003). This and similar programs could serve as models to develop a more comprehensive national system.

There are other ways in which risk-assessment models can be improved. Risk-assessment models should do a better job of addressing uncertainty, because this is a vital component of thorough risk assessment (National Research Council 2009). Few risk-assessment models have systematically incorporated uncertainty analysis into their design, but doing so has been given recent attention (e.g. Caley et al. 2006, Benke et al. 2011). Basic sensitivity analysis to determine variable importance, such as the one incorporated in Parker et al. (2007) or in Chapter 2 of this thesis, is one step that can help fill this gap. The human element is also not well-incorporated into risk-assessment models. Plant characteristics, taxonomic patterns, and biogeography are important, but humans are also well-recognized as factors mediating plant invasion. For example, strong positive correlations have been observed between human population densities and the density of naturalized plants, and countries with more extensive transportation networks also have a higher density of naturalized plants (Vilá and Pujadas 2001). Weber and Gut (2004) incorporate a pre-screening procedure in their risk-assessment system that incorporates aspects of the human dimensions of plant invasion (e.g. how widely distributed will the species be in the area?), and systems may improve if these and other protocols are more widely used.

Risk-assessment models will likely need to be periodically updated and revised. The current era of rapid global climate change is likely to lead to increased risk for plant invasions. An assessment of three invasive species in the southeastern United States projects that one of the worst invasive species – kudzu (*Pueraria lobata*) – could expand as far north as Ohio by 2100 CE (Bradley et al. 2010). This further reinforces the iterative nature of risk analysis. Conditions are constantly shifting, so models that are accurate predictors of naturalization and invasion today may quickly become outdated due environmental change. Accounting for these changes could be made easier with dynamic databases of plant information as proposed earlier.

There are additional questions beyond the science involved in risk analysis. A strong precedent has been set for viewing invasive species as bad, harmful entities that ought to be controlled and managed. While aspects of this viewpoint can be supported by the science of invasion biology, others are grounded in more subjective, value-driven judgments. What we "ought" to do about invasive species is a question of ethics, not strictly of science. Although scientists sometimes give the impression that the idea of native and non-native species is a matter of fact, the drawing of lines in either time or space is ultimately a somewhat arbitrary process (Warren 2007). This and other points of discerning invasive from non-invasive species have been challenged (Brown and Sax 2004, Sagoff 2005), and has prompted a number of ecologists to propose we assess species based on impact, not on origin (Davis et al. 2011). However, this does not completely resolve the issue. Invasive species are regarded as something bad and to be corrected, but this involves not only normative value judgments (i.e. what nature "ought" to be) but potentially problematic definitions of what "harm" to the environment means. When designating a species as "invasive" may essentially condemn it to systematic eradication, an understanding of these nuances is important from the standpoint of environmental ethics.

Regardless of how we individually and collectively answer these scientific and ethical challenges, invasion biology remains an important area of inquiry. To learn more about the world around us, even if we do not successfully manage invasive plants, adds to an ever-growing body of information that can be of benefit for years to come.

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APPENDIX A

ILLUSTRATION OF DECISION TREES

The following pages illustrate four risk-assessment models described in Chapter 2 of my thesis. Because of the nature of the random forest model (an averaging of many decision trees), it is not possible to depict it as a figure.

Figure 1 is a reproduction of the 'continental decision tree' (Reichard and Hamilton 1997). The continental decision tree is the basis of the next two risk-assessment models that follow.

Figure 2 depicts the refinements made to the continental decision tree to produce the 'modified decision tree' (Widrlechner et al. 2004).

Figure 3 illustrates the refinements made to the continental decision tree to produce the 'decision tree/matrix model' (Widrlechner et al. 2004).

Figure 4 is a reproduction of the 'CART model' (Widrlechner et al. 2004).

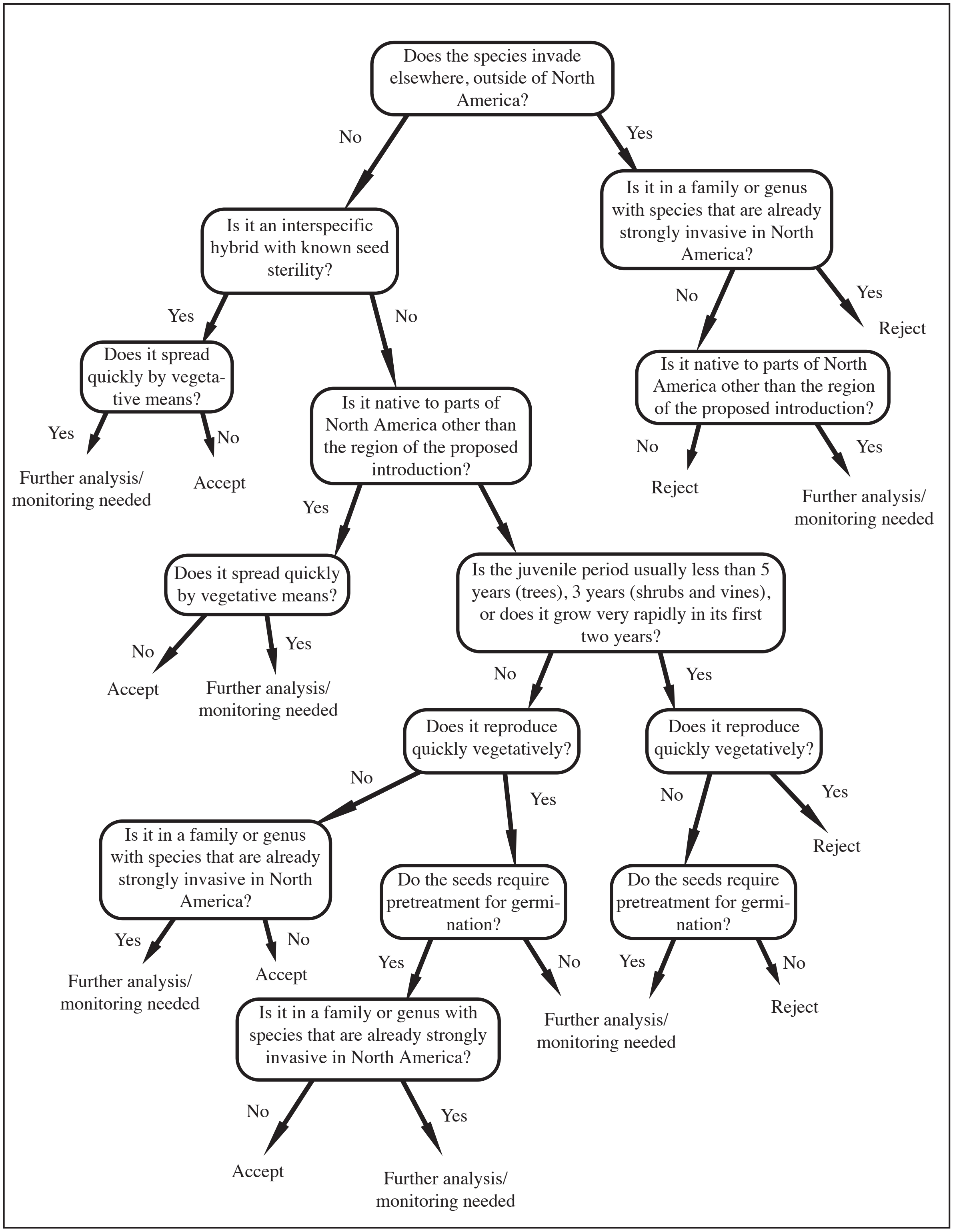

Figure 1. Continental decision tree.

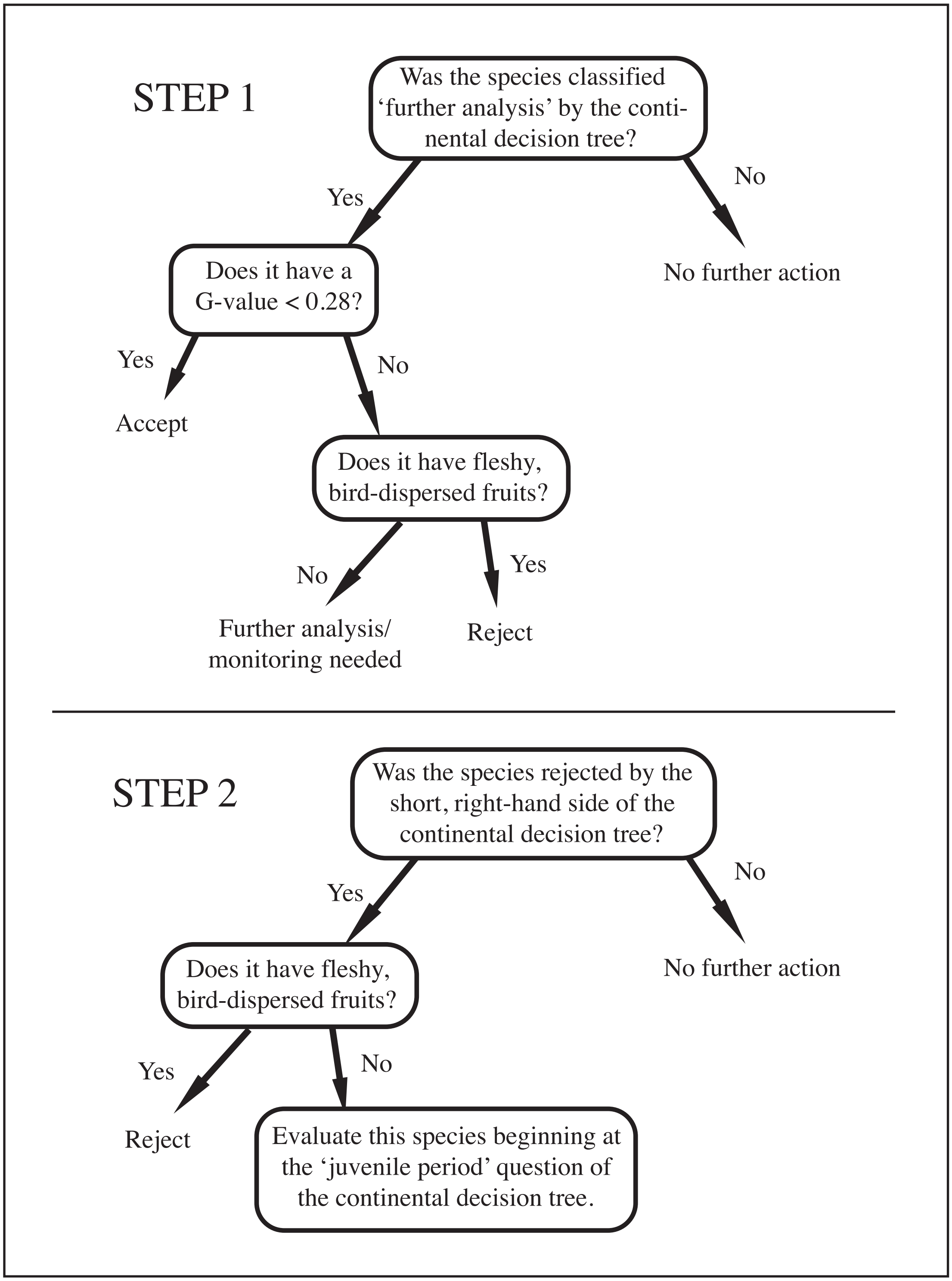

Figure 2. Modified decision tree.

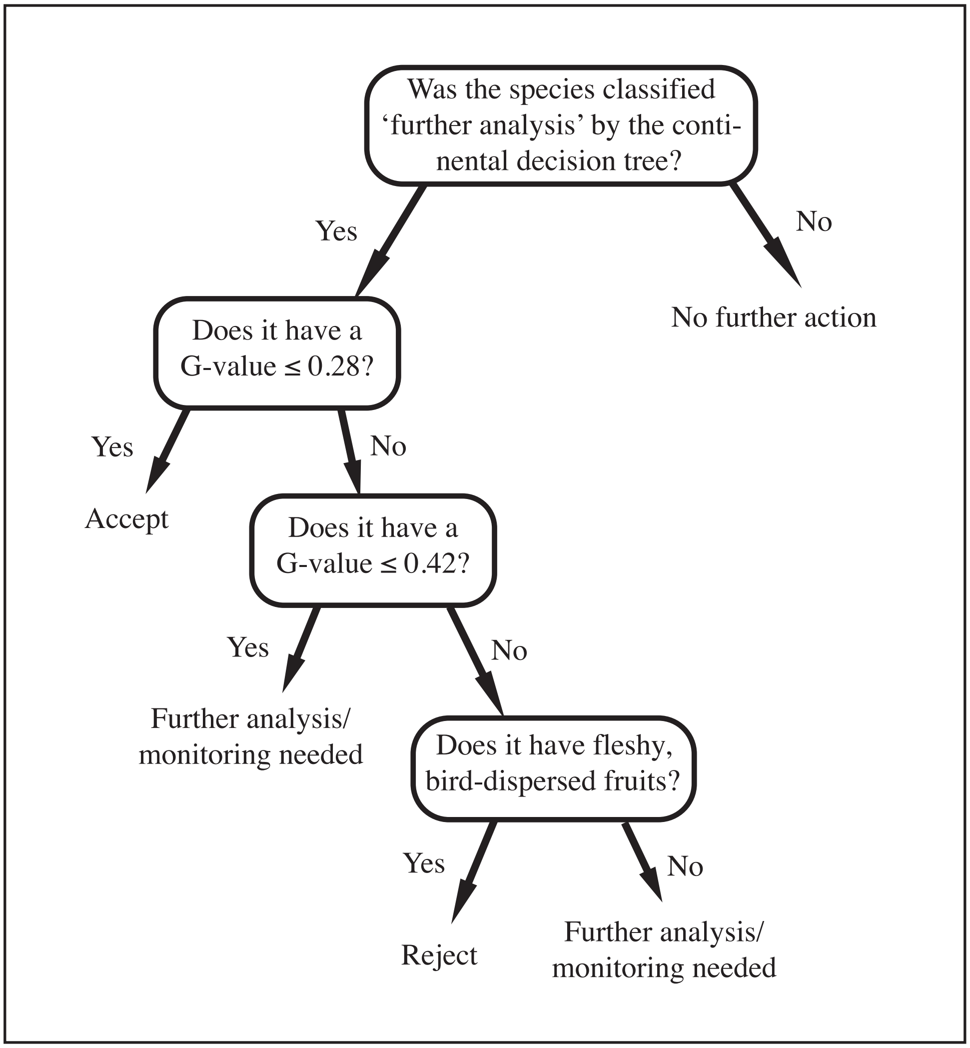

Figure 3. Decision tree/matrix model.

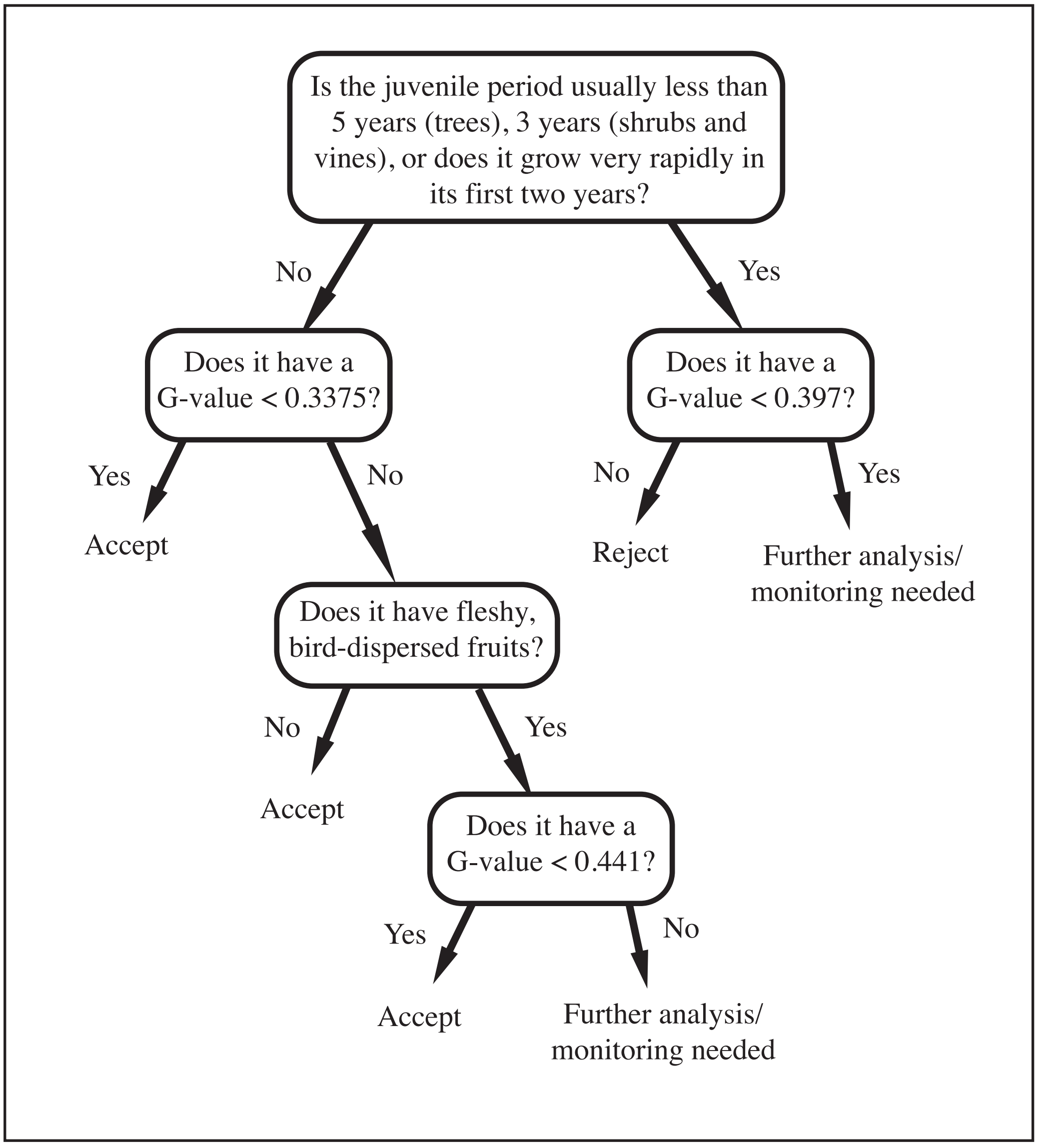

Figure 4. CART model.

APPENDIX B

EXAMPLE OF SURVEY INSTRUMENT

The following pages contain the survey instrument sent to professional horticulturists; it is formatted exactly as the respondents would have seen it as hosted on SurveyMonkey™ .

Iowa Plants Survey - Professional Horticulturist/Landscaper

1. Iowa Plants Survey - Informed Consent

Dear professional horticulturist,

Personnel at Iowa State University are conducting a research study on attitudes towards non-native plants in the state of Iowa. You have been selected as a potential participant because you are an important stakeholder in future decision-making regarding non-native plants. We would like to invite you to participate in a short online survey that will offer us insight into your opinions on this issue. Please carefully consider if you are willing to participate.

There are no direct risks or benefits to you should you choose to participate in this study. Your participation is completely voluntary and you may skip any questions that you do not wish to answer or that make you feel uncomfortable.

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publically available. However, federal government regulatory agencies, auditing departments of Iowa State University, and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy project records for quality assurance and data analysis. These records may contain private information. To ensure confidentiality to the extent permitted by law, any potentially identifying information will be replaced with a unique code that cannot be used to identify you personally. If the results of this study are published, your identity will remain completely confidential.

Your participation in this research project is very important to us. We thank you for considering participating in this important study.

By clicking ‘NEXT’ now, you will become a participant in our study.

• For further information about the study or if you have questions regarding the study, contact Dr. Jan Thompson (jrrt@iastate.edu) or Em Kapler (ekapler@iastate.edu), Department of Natural Resource Ecology and Management, 339 Science II, Iowa State University, Ames, IA.

• If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.

Iowa Plants Survey - Professional Horticulturist/Landscaper

2. Iowa Plants Survey

Welcome to the Iowa plants survey! First we'd like to confirm which stakeholder group you represent. These are the only two questions that are required in our survey.

*** Please select your primary group affiliation.**

- Professional horticulturist and/or landscaper
- Master gardener and/or recreational gardener
- Natural resource manager and/or conservation professional
- Woodland landowner

*** Please select your secondary group affiliation, if applicable.**

- Professional horticulturist and/or landscaper
- Master gardener and/or recreational gardener
- Natural resource manager and/or conservation professional
- Woodland landowner
- Not applicable

Iowa Plants Survey - Professional Horticulturist/Landscaper

3. Iowa Plants Survey

How would you describe your interest in plants? Please select only your three favorite interests. Some examples are given in parenthesis following each category.

- ☐ Cultivating plants for food (fruit and vegetable gardens)
- ☐ Wild harvesting of plants for food (foraging wild berries, nuts)
- ☐ Gardening/landscaping at home (gardening with annuals, perennials, trees, shrubs)
- ☐ Gardening/landscaping as a profession (working at nursery, developing new cultivars, marketing)
- ☐ Gardening/landscaping for conservation/land management (rain gardens, wind breaks, prairie restoration)
- ☐ Visiting cultivated displays of plants (greenhouses, botanical centers, parks)
- ☐ Visiting natural areas with plants (forest preserves, prairie remnants, wetlands)
- ☐ Harvesting plant materials for arts and crafts (homemade dyestuffs, wreath making, flower pressing)
- ☐ Religious or spiritual appreciation of plants (folklore, mythology, ritual uses, worship)
- ☐ Using plants for medicinal purposes (herbal remedies such as echinacea, ginseng)
- ☐ Studying/researching sciences relating to plants (ethnobotany, plant ecology, plant anatomy)

Other (please specify)

How would you describe your level of knowledge about plants?

- ○ Minimal
- ○ Low
- ○ Fair
- ○ Good
- ○ Excellent

Iowa Plants Survey - Professional Horticulturist/Landscaper

4. Iowa Plants Survey

Now we'd like to ask some questions about how you relate to or feel about the natural world in general. There are no right or wrong answers, so please be as honest as you can. There will be three pages in this section.

Please rate how much you agree or disagree with the following items.

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
Even in the middle of the city, I notice nature around me	○	○	○	○	○
Conservation is unnecessary because nature is strong enough to recover from any human impact	○	○	○	○	○
I enjoy being outdoors, even in unpleasant weather	○	○	○	○	○
I feel very connected to all living things and the earth	○	○	○	○	○
Animals, birds, and plants should have fewer rights than humans	○	○	○	○	○
I am very aware of environmental issues	○	○	○	○	○
My ideal vacation spot would be a remote, wilderness area	○	○	○	○	○

Iowa Plants Survey - Professional Horticulturist/Landscaper

5. Iowa Plants Survey

Please continue answering questions about how you relate to or feel about the natural world in general. Remember, there are no right or wrong answers.

Please rate how much you agree or disagree with the following items.

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
Humans have the right to use natural resources any way we want	◯	◯	◯	◯	◯
My connection to nature and the environment is part of my spirituality	◯	◯	◯	◯	◯
My relationship to nature is an important part of who I am	◯	◯	◯	◯	◯
I don't often go out in nature	◯	◯	◯	◯	◯
The state of nonhuman species is an indicator of the future for humans	◯	◯	◯	◯	◯
Some species are just meant to die out and become extinct	◯	◯	◯	◯	◯
I usually think about how my actions affect the environment	◯	◯	◯	◯	◯

Iowa Plants Survey - Professional Horticulturist/Landscaper

6. Iowa Plants Survey

This is the final page of questions about how you relate to or feel about the natural world in general. Remember, there are no right or wrong answers.

Please rate how much you agree or disagree with the following items.

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
I take notice of wildlife wherever I am	◯	◯	◯	◯	◯
I am not separate from nature, but a part of nature	◯	◯	◯	◯	◯
The thought of being in the deep woods, away from civilization, is frightening	◯	◯	◯	◯	◯
My feelings about nature do not affect how I live my life	◯	◯	◯	◯	◯
I enjoy digging in the earth and getting dirt on my hands	◯	◯	◯	◯	◯
Nothing I do will change problems in other places on the planet	◯	◯	◯	◯	◯
I think a lot about the suffering of animals	◯	◯	◯	◯	◯

Iowa Plants Survey - Professional Horticulturist/Landscaper

7. Iowa Plants Survey

In this section we would like to ask you some questions about environmental issues. Many environmental issues are relevant across the globe, but think about these issues on a more local scale.

Based on the needs of the state of Iowa, how would you prioritize efforts in each of the following areas?

	Lowest priority	Low priority	Medium priority	High priority	Highest priority
Improving water quality (e.g. in lakes, rivers)	◯	◯	◯	◯	◯
Preserving natural areas	◯	◯	◯	◯	◯
Managing invasive species	◯	◯	◯	◯	◯
Developing sustainable energy	◯	◯	◯	◯	◯
Managing solid waste	◯	◯	◯	◯	◯
Preventing soil erosion	◯	◯	◯	◯	◯

A potential environmental concern we'd like to focus on in this survey is invasive plants. Have you heard the term "invasive plants" before?

◯ Yes

◯ No

◯ Unsure

Iowa Plants Survey - Professional Horticulturist/Landscaper

8. Iowa Plants Survey

Where have you heard about invasive plants? Please select all that apply.

- [ ] Radio or podcast
- [ ] Television or internet video
- [ ] Newspaper, magazine, or book
- [ ] Internet website
- [ ] Friends or family
- [ ] Colleagues
- [ ] Plant retailers, nurseries
- [ ] Conservation professionals
- [ ] Educators or at a workshop/lecture

Other (please specify)

Iowa Plants Survey - Professional Horticulturist/Landscaper

9. Iowa Plants Survey

In your own words, what do you think it means for something to be an invasive plant? There will be space for you to type about three sentences for your answer.

Iowa Plants Survey - Professional Horticulturist/Landscaper

10. Iowa Plants Survey

Based on what you think it means for a plant to be invasive, please rate how much you agree or disagree with these statements about invasive plants.

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
Invasive plants are the same thing as weeds	○	○	○	○	○
If it grows where I don't want it, it is an invasive plant to me	○	○	○	○	○
Invasive plants aren't necessarily bad plants	○	○	○	○	○
In general, I don't see invasive plants as a problem	○	○	○	○	○

Iowa Plants Survey - Professional Horticulturist/Landscaper

11. Iowa Plants Survey

For the next few questions, we'd like you to keep in mind the following information.

When we say a plant is non-native in this survey, we mean it was not found in Iowa before people brought it here from other parts of the world.

For the remainder of this survey, an invasive plant is a non-native plant that can reproduce and spread aggressively into areas where it was not planted. Invasive plants tend to displace plants that were in that area before, changing how the landscape looks and what types wildlife can live there. Invasive plants can impact all types of landscapes, from urban and suburban ones, to parks, gardens, farmlands, and nature preserves.

Please rate how much you agree or disagree with these statements about invasive plants, keeping in mind the definitions above.

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
If a plant is invasive we should just let nature take its course and not interfere	○	○	○	○	○
We should only manage invasive plants if they cause trouble for people	○	○	○	○	○
We have a responsibility to help protect our natural areas from invasive plants	○	○	○	○	○
State laws or mandates should be passed to adequately manage invasive plants	○	○	○	○	○
Invasive plants should be managed on a voluntary basis	○	○	○	○	○

Please rate how much you agree or disagree with these statements about invasive plants, keeping in mind the definitions above.

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
Professional horticulturists should take a leadership role on the issue of invasive plants	○	○	○	○	○
I am concerned that we have sold or cultivated invasive plants	○	○	○	○	○
Introducing new and interesting plants is more important than worrying about if these plants will become invasive	○	○	○	○	○

Iowa Plants Survey - Professional Horticulturist/Landscaper

12. Iowa Plants Survey

Some scientists who study invasive plants feel that screening non-native plants prior to sale or release is a good management strategy. This screening process is called risk assessment and uses information about the plants and statistical tools to determine if a plant is likely to become invasive. Scientists look at characteristics of the plant to make a risk assessment. One type of statistical model ends with three results: accept, reject, or further analysis.

Accept means the plant is unlikely to become invasive. We can sell and use this plant freely without much worry.

Reject means the plant is likely to become invasive. We would avoid or limit sale and use of this plant.

Further analysis means we're not sure if the plant will become invasive. We should study it more before widely selling or using it.

Based on this information, please indicate how much you agree or disagree with the following statements regarding risk assessment.

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
I think risk assessment has the potential to prevent future plant invasions	○	○	○	○	○
I am skeptical about how effective risk assessment could be	○	○	○	○	○
I don't think we should use risk assessment	○	○	○	○	○
I am concerned about the accuracy of risk assessment	○	○	○	○	○
I am willing to use results from risk assessment in my business decisions	○	○	○	○	○
I am willing to conduct field trials on plants classified as "further analysis"	○	○	○	○	○
If the risk assessment model rejected a plant, I would discontinue sale of it	○	○	○	○	○
I would discontinue sale of a rejected plant even if it had a high profit margin	○	○	○	○	○

Iowa Plants Survey - Professional Horticulturist/Landscaper

13. Iowa Plants Survey

Risk assessment models that screen non-native plants for invasive potential may produce some errors. We'd like you to think about these for a moment.

Horticulturally limiting error means a plant was falsely rejected and would not have become an invasive plant. This could represent lost profits for nurseries and fewer choices on the market.

Biologically significant error means a plant was falsely accepted and becomes a new invasive plant. This could lead to undesired changes in our landscapes and wildlife.

Scientists developing risk assessment models that screen non-native plants for invasive potential work to minimize errors, but no model will be error-free. Taking this into consideration, in your opinion, what is the maximum percent error you think is acceptable for a risk assessment model?

Horticulturally limiting error

Biologically significant error

Iowa Plants Survey - Professional Horticulturist/Landscaper

14. Iowa Plants Survey

The following questions are for classification purposes only.

Are you:

- ○ Male
- ○ Female

In what year were you born? (format example: 1956)

Approximately how many years have you lived in Iowa?

What is the highest level of education that you have completed?

- ○ Less than 9th grade
- ○ 9th to 12th grade, no diploma
- ○ High school graduate
- ○ Some college, no degree
- ○ Associate degree
- ○ Bachelor's degree
- ○ Graduate or professional degree
- ○ Prefer not to answer

Iowa Plants Survey - Professional Horticulturist/Landscaper

What best describes your annual household income?

- Less than $10,000
- $10,000-14,999
- $15,000-24,999
- $25,000-34,999
- $35,000-49,999
- $50,000-74,999
- $75,000-99,999
- $100,000-149,999
- $150,000-199,999
- $200,000 or more
- Prefer not to answer

Iowa Plants Survey - Professional Horticulturist/Landscaper

15. Iowa Plants Survey

Thank you for your participation in this important study. We appreciate your time and consideration!

Have a great Autumn!

APPENDIX C

SURVEY DATA SUMMARY

Following is a detailed summary of survey responses by stakeholder group, including questions not discussed in Chapter 3. All values are in number of respondents. Questions shaded light gray represent reverse-coded items in the nature relatedness scale. If no values appear for a group, the question was not asked of that group.

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
Please select your primary group affiliation				
Conservation professional	130	3	0	7
Master gardener	0	200	1	4
Professional horticulturists	0	4	59	1
Woodland landowner	0	0	0	62
Please select your secondary group affiliation				
Conservation professional	8	4	3	7
Master gardener	22	27	16	23
Professional horticulturists	3	3	11	2
Woodland landowner	33	32	8	19
Not applicable	64	141	22	23
How would you describe your interest in plants?				
Cultivating plants for food	43	128	14	25
Wild harvesting of plants for food	26	10	3	14
Gardening/landscaping at home	46	192	33	41
Gardening/landscaping as a profession	6	9	55	3
Gardening/landscaping for conservation/land management	85	40	11	45
Visiting cultivated displays of plants	10	119	20	13
Visiting natural areas with plants	109	71	22	46
Harvesting plant materials for arts and crafts	2	15	2	7
Religious or spiritual	2	1	0	0

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
appreciation of plants				
Using plants for medicinal purposes	2	11	0	3
Studying/researching sciences relating to plants	42	5	6	3
Other	5	7	0	6
Total N (plant interests)	130	207	60	74
How would you describe your knowledge level about plants?				
Minimal	0	1	0	0
Low	5	9	0	8
Fair	33	72	1	24
Good	73	111	29	37
Excellent	18	13	29	5
NR-Self Subscale				
My connection to nature and the environment is part of my spirituality				
Strongly disagree	6	6	3	4
Disagree	12	20	7	5
Unsure	22	27	5	11
Agree	65	107	34	41
Strongly agree	25	47	11	13
My relationship to nature is an important part of who I am				
Strongly disagree	0	0	1	1
Disagree	1	5	1	3
Unsure	1	4	2	6
Agree	62	132	28	31
Strongly agree	66	66	28	32
I feel very connected to all living things and the earth				
Strongly disagree	0	0	0	1
Disagree	6	5	2	3
Unsure	17	22	6	8
Agree	66	106	29	36
Strongly agree	41	74	23	26
I am not separate from nature, but a part of nature				
Strongly disagree	1	1	1	1
Disagree	5	3	1	0
Unsure	10	12	0	3
Agree	68	115	33	40
Strongly agree	46	76	25	30

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
I usually think about how my actions affect the environment				
Strongly disagree	0	0	0	0
Disagree	4	2	1	1
Unsure	5	3	3	3
Agree	81	147	40	45
Strongly agree	40	55	16	25
I am very aware of environmental issues				
Strongly disagree	1	3	0	0
Disagree	1	6	1	1
Unsure	4	16	4	5
Agree	69	135	40	41
Strongly agree	55	47	15	27
I think a lot about the suffering of animals				
Strongly disagree	16	10	5	7
Disagree	59	54	22	26
Unsure	28	44	14	16
Agree	24	69	15	19
Strongly agree	3	30	4	6
Even in the middle of the city, I notice nature around me				
Strongly disagree	1	1	2	1
Disagree	6	1	1	0
Unsure	3	4	1	0
Agree	62	80	16	39
Strongly agree	58	121	40	34
My feelings about nature do not affect how I live my life				
Strongly disagree	62	60	20	40
Disagree	57	130	32	31
Unsure	5	3	4	2
Agree	4	13	2	1
Strongly agree	2	1	2	0
NR-Experience Subscale				
Humans have the right to use natural resources any way we want				
Strongly disagree	55	99	20	38
Disagree	66	91	33	30
Unsure	1	8	3	3
Agree	8	6	4	1
Strongly agree	0	3	0	2
Conservation is unnecessary because nature is strong enough to recover from any human impact				
Strongly disagree	103	151	36	56
Disagree	23	52	22	18
Unsure	1	2	2	0
Agree	0	1	0	0
Strongly agree	3	1	0	0

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
Animals, birds, and plants should have fewer rights than humans				
Strongly disagree	23	57	11	11
Disagree	22	47	16	13
Unsure	28	59	11	19
Agree	36	34	14	21
Strongly agree	21	10	8	10
Nothing I do will change problems in other places on the planet				
Strongly disagree	42	63	17	29
Disagree	72	106	33	33
Unsure	11	24	6	7
Agree	3	12	4	4
Strongly agree	2	2	0	1
Some species are just meant to die out and become extinct				
Strongly disagree	27	35	11	17
Disagree	39	65	16	20
Unsure	34	61	12	23
Agree	27	42	17	11
Strongly agree	3	4	4	3
The state of nonhuman species is an indicator of the future for humans				
Strongly disagree	1	4	3	2
Disagree	7	10	2	5
Unsure	18	50	13	15
Agree	61	84	26	27
Strongly agree	43	59	16	25
NR-Experience Subscale				
I enjoy being outdoors, even in unpleasant weather				
Strongly disagree	0	3	1	0
Disagree	1	32	2	2
Unsure	4	12	5	2
Agree	66	114	38	39
Strongly agree	59	46	14	31
My ideal vacation spot would be a remote, wilderness area				
Strongly disagree	0	13	2	0
Disagree	10	62	12	7
Unsure	15	47	8	19
Agree	62	52	21	30
Strongly agree	43	33	17	18
I don’t often go out in nature				
Strongly disagree	97	113	36	56
Disagree	28	83	21	17
Unsure	0	3	0	0
Agree	3	3	3	1
Strongly agree	2	5	0	0

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
I take notice of wildlife wherever I am				
Strongly disagree	0	0	0	0
Disagree	0	1	0	0
Unsure	4	1	0	1
Agree	49	112	34	27
Strongly agree	77	93	26	46
The thought of being in the deep woods, away from civilization, is frightening				
Strongly disagree	46	51	25	44
Disagree	78	113	30	23
Unsure	4	17	3	7
Agree	1	25	1	0
Strongly agree	1	1	1	0
I enjoy digging in the earth and getting dirt on my hands				
Strongly disagree	1	2	0	1
Disagree	1	0	2	1
Unsure	4	0	1	3
Agree	78	61	22	36
Strongly agree	46	144	35	33
Based on the needs of the state of Iowa, how would you prioritize efforts in each of the following areas?				
Improving water quality				
Lowest priority	0	0	1	0
Low priority	0	2	1	0
Medium priority	7	21	8	6
High priority	48	100	28	33
Highest priority	74	84	22	35
Preserving natural areas				
Lowest priority	1	0	1	2
Low priority	1	2	0	0
Medium priority	14	41	12	8
High priority	59	115	38	41
Highest priority	55	48	9	23
Managing invasive species				
Lowest priority	1	2	0	0
Low priority	5	9	5	3
Medium priority	30	50	24	23
High priority	62	93	25	29
Highest priority	32	50	5	19
Developing sustainable energy				
Lowest priority	2	0	0	2
Low priority	11	3	4	1
Medium priority	39	30	18	15
High priority	48	82	26	34
Highest priority	22	92	11	20

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
Managing solid waste				
Lowest priority	4	2	1	0
Low priority	9	7	5	5
Medium priority	45	50	16	11
High priority	49	97	32	13
Highest priority	23	49	6	14
Preventing soil erosion				
Lowest priority	0	3	0	0
Low priority	2	1	1	0
Medium priority	14	26	6	5
High priority	53	110	39	34
Highest priority	61	66	14	35
Have you heard the term "invasive plants" before?				
Yes	129	206	59	74
No	0	0	0	0
Unsure	0	1	0	0
Where have you heard about invasive plants? Please select all that apply.				
Radio or podcast	55	67	22	27
Television or internet video	54	89	24	28
Newspaper, magazine, or book	107	173	43	63
Internet website	97	104	36	48
Friends or family	74	90	22	34
Colleagues	119	92	48	40
Plant retailers, nurseries	15	72	37	9
Conservation professionals	130	112	49	60
Educators or at a workshop/lecture	108	171	56	48
OTHER	1	12	0	4
In your own words, what do you think it means for something to be an invasive plant?				
Mentioned invasive plants are non-native	95	72	21	42
Mentioned invasive plants can be native	20	12	2	5
Mentioned aggressive spread and/or reproduction	45	127	30	35
Mentioned displacement of desired/native vegetation and/or harm to environment	95	154	36	54
Mentioned few/no natural controls on spread/growth	12	14	5	7
Mentioned management is difficult	5	34	7	2
Met critera for understanding	104	193	50	51

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
Did not meet criteria for understanding	26	7	4	8
Invasive plants are the same thing as weeds				
Strongly disagree	17	33	11	16
Disagree	84	119	27	38
Unsure	5	16	5	6
Agree	18	29	14	10
Strongly agree	6	9	3	4
If it grows where I don't want it, it is an invasive plant to me				
Strongly disagree	26	35	14	14
Disagree	87	98	33	36
Unsure	4	16	3	6
Agree	11	43	9	14
Strongly agree	2	14	1	3
Invasive plants aren't necessarily bad plants				
Strongly disagree	17	19	2	8
Disagree	42	31	13	14
Unsure	14	26	7	11
Agree	54	113	33	36
Strongly agree	3	14	5	5
In general, I don't see invasive plants as a problem				
Strongly disagree	77	72	18	37
Disagree	49	100	27	28
Unsure	2	18	7	5
Agree	1	13	8	1
Strongly agree	1	1	0	3
If a plant is invasive we should just let nature take its course and not interfere				
Strongly disagree	75	108	12	38
Disagree	49	83	41	29
Unsure	4	11	5	5
Agree	2	2	1	0
Strongly agree	0	1	1	1
We should only manage invasive plants if they cause trouble for people				
Strongly disagree	65	83	15	32
Disagree	54	97	28	35
Unsure	4	12	7	4
Agree	6	11	9	2
Strongly agree	1	2	1	0
We gave a responsibility to help protect our natural areas from invasive plants				
Strongly disagree	7	14	0	2
Disagree	2	3	3	3
Unsure	2	10	6	2
Agree	48	94	33	35
Strongly agree	71	83	18	31

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
State laws or mandates should be passed to adequately manage invasive plants				
Strongly disagree	8	7	2	1
Disagree	5	16	11	10
Unsure	25	61	15	22
Agree	55	78	25	27
Strongly agree	37	43	7	13
Invasive plants should be maanged on a voluntary basis				
Strongly disagree	25	39	10	10
Disagree	60	83	26	25
Unsure	23	39	10	16
Agree	18	38	11	16
Strongly agree	3	6	3	5
I am concerned that we have used invasive plants for management projects				
Strongly disagree	3			
Disagree	16			
Unsure	8			
Agree	73			
Strongly agree	30			
Other conservation or land management issues should take a higher priority than invasive species				
Strongly disagree	7			
Disagree	44			
Unsure	43			
Agree	34			
Strongly agree	2			
Managing invasive species is fighting a losing battle				
Strongly disagree	13			
Disagree	71			
Unsure	32			
Agree	12			
Strongly agree	2			
I learned about invasive plants in my master gardener program				
Strongly disagree		4		
Disagree		22		
Unsure		16		
Agree		140		
Strongly agree		23		
I'm concerned that I may have used invasive plants in my gardening				
Strongly disagree		20		
Disagree		93		
Unsure		27		
Agree		60		
Strongly agree		5		

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
Master gardeners should take a leadership role on the issue of invasive plants				
Strongly disagree		3		
Disagree		2		
Unsure		23		
Agree		121		
Strongly agree		55		
Professional horticulturists should take a leadership role on the issue of invasive plants				
Strongly disagree			0	
Disagree			1	
Unsure			6	
Agree			40	
Strongly agree			13	
I am concerned that we have sold or cultivated invasive plants				
Strongly disagree			3	
Disagree			15	
Unsure			8	
Agree			29	
Strongly agree			5	
Introducing new and interesting plants is more important than worrying about if these plants will become invasive				
Strongly disagree			15	
Disagree			32	
Unsure			8	
Agree			5	
Strongly agree			0	
I'm concerned about the impact of invasive plants on my own property				
Strongly disagree				1
Disagree				3
Unsure				4
Agree				28
Strongly agree				37
It's my responsibility to deal with the invasive plants on my property				
Strongly disagree				0
Disagree				2
Unsure				5
Agree				37
Strongly agree				28
It would concern me if a plant was invading on property close to my own				
Strongly disagree				0
Disagree				0
Unsure				3
Agree				44
Strongly agree				25

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
I think risk assessment has the potential to prevent future plant invasions				
Strongly disagree	1	1	1	4
Disagree	13	6	2	2
Unsure	22	27	8	11
Agree	85	125	41	39
Strongly agree	9	43	5	16
I am skeptical about how effective risk assessment could be				
Strongly disagree	4	16	2	4
Disagree	32	88	15	25
Unsure	34	47	14	16
Agree	57	47	25	24
Strongly agree	3	2	1	3
I don't think we should use risk assessment				
Strongly disagree	16	43	9	16
Disagree	76	118	28	35
Unsure	30	35	18	17
Agree	8	5	1	1
Strongly agree	0	0	0	3
I am concerned about the accuracy of risk assessment				
Strongly disagree	2	11	3	2
Disagree	14	59	8	16
Unsure	31	56	11	22
Agree	81	67	31	28
Strongly agree	2	4	4	4
I am willing to use results from risk assessment to guide land management decisions				
Strongly disagree	0			
Disagree	15			
Unsure	43			
Agree	61			
Strongly agree	11			
I would rather buy plants from a retailer who has used risk assessment				
Strongly disagree		0		
Disagree		7		
Unsure		18		
Agree		127		
Strongly agree		49		
I would be willing to pay more for a plant sold by a retailer who had used risk assessment				
Strongly disagree		1		
Disagree		22		
Unsure		54		
Agree		94		
Strongly agree		29		

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
I am willing to use results from risk assessment in my buisiness decisions				
Strongly disagree			0	
Disagree			1	
Unsure			13	
Agree			39	
Strongly agree			4	
I am willing to conduct field trials on plants classified as "further analysis"				
Strongly disagree			1	
Disagree			12	
Unsure			11	
Agree			30	
Strongly agree			2	
If the risk assesment model rejected a plant, I would disconitinue sale of it				
Strongly disagree			1	
Disagree			4	
Unsure			17	
Agree			27	
Strongly agree			7	
I would discontinue sale of a rejected plant even if it had a high profit margin				
Strongly disagree			0	
Disagree			3	
Unsure			21	
Agree			24	
Strongly agree			7	
Biologically significant error				
≤ 5%	68	66	14	33
6-10%	16	33	10	13
11-15%	0	7	1	1
16-20%	5	12	3	1
21-25%	6	10	1	1
26%-49%	0	3	0	0
≥ 50%	4	29	3	6
Horticulturally limiting error				
≤ 5%	21	23	9	17
6-10%	27	41	10	14
11-15%	3	8	0	3
16-20%	10	17	5	5
21-25%	8	25	2	5
26%-49%	2	9	3	1
≥ 50%	23	36	4	10

Survey question and scale	Stakeholder group			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
Demographics				
Males	94	42	36	56
Females	32	154	21	12
Age 18-30	13	2	7	1
Age 31-50	72	31	25	14
Age 51-70	39	142	24	49
Age 71+	0	20	0	6
1-15 years in Iowa	16	13	2	2
16-30 years in Iowa	21	21	14	10
31-45 years in Iowa	45	34	14	14
46-60 years in Iowa	40	80	19	30
61-75 years in Iowa	2	43	2	12
76+ years in iowa	0	4	0	2
Education				
<9th Grade	0	0	0	0
No Diploma	0	0	0	0
High School	1	20	2	5
Some College	1	29	5	10
Associates	6	28	13	4
Bachelor's	86	69	29	28
Graduate	32	49	7	24
No Answer	0	2	1	0
Income				
<$10k	0	1	0	0
$10-14K	1	0	0	0
$15-24k	0	4	0	2
$25-34k	1	9	2	1
$35-49k	12	20	9	6
$50-74k	45	38	11	14
$75-99k	32	30	10	15
$100-149k	22	20	8	8
$150-199k	0	9	5	7
$200k+	0	3	2	5
No Answer	11	58	8	12

APPENDIX D

NATURE RELATEDNESS SUBSCALE CORRELATIONS

The following are tables showing correlations of the survey questions presented in Table 8 in Chapter 3 with the NR-Self, NR-Perspective, and NR-Experience subscales.

Survey Question	NR-Self correlation (r)			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
1. In general, I don't see invasive plants as a problem.	- 0.36 ***	- 0.09	- 0.41 **	- 0.10
2. If a plant is invasive we should just let nature take its course and not interfere.	- 0.34 ***	- 0.28 ***	- 0.18	- 0.14
3. We should only manage plants if they cause trouble for people.	- 0.45 ***	- 0.30 ***	- 0.23	- 0.19
4. We have a responsibility to protect our natural areas from invasive plants.	0.36 ***	0.16 *	0.38 **	0.37 **
5. State laws or mandates should be passed to adequately manage invasive plants.	0.24 **	0.13	0.34 **	0.28 *
6. Invasive plants should be managed on a voluntary basis.	- 0.17	- 0.11	- 0.23	- 0.08
7. I don't think we should use risk assessment.	- 0.21 *	- 0.19 **	- 0.28 *	- 0.04
Biologically significant error	0.04	-0.19 *	- 0.03	0.04
Horticulturally limiting error	0.16	-0.21 *	0.28	0.03

* value is statistically significant at $P \leq 0.05$
** value is statistically significant at $P \leq 0.01$
*** value is statistically significant at $P \leq 0.001$

Survey Question	NR-Perspective correlation (r)			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
1. In general, I don't see invasive plants as a problem.	- 0.31 ***	- 0.05	- 0.45 ***	- 0.01
2. If a plant is invasive we should just let nature take its course and not interfere.	- 0.39 ***	- 0.23 ***	- 0.43 ***	- 0.12
3. We should only manage plants if they cause trouble for people.	- 0.38 ***	- 0.29 ***	- 0.43 ***	- 0.05
4. We have a responsibility to protect our natural areas from invasive plants.	0.34 ***	0.22 **	0.44 ***	0.24 *
5. State laws or mandates should be passed to adequately manage invasive plants.	0.14	0.17 *	0.30 *	0.35 **
6. Invasive plants should be managed on a voluntary basis.	- 0.22 *	- 0.22 **	- 0.50 ***	- 0.17
7. I don't think we should use risk assessment.	- 0.13	- 0.16 *	- 0.26 *	0.01
Biologically significant error	- 0.01	- 0.13	0.02	- 0.04
Horticulturally limiting error	0.02	- 0.14	0.41*	0.00

* value is statistically significant at $P \leq 0.05$

** value is statistically significant at $P \leq 0.01$

*** value is statistically significant at $P \leq 0.001$

Survey Question	NR-Experience correlation (r)			
	Conservation professionals	Master gardeners	Professional horticulturists	Woodland landowners
1. In general, I don't see invasive plants as a problem.	- 0.32 ***	- 0.12	- 0.36 **	- 0.27 *
2. If a plant is invasive we should just let nature take its course and not interfere.	- 0.32 ***	- 0.25 ***	- 0.06	- 0.30 *
3. We should only manage plants if they cause trouble for people.	- 0.29 **	- 0.25 ***	- 0.11	- 0.29 *
4. We have a responsibility to protect our natural areas from invasive plants.	0.35 ***	0.26 ***	0.21	0.41 ***
5. State laws or mandates should be passed to adequately manage invasive plants.	0.20 *	0.20 **	0.28 *	0.26 *
6. Invasive plants should be managed on a voluntary basis.	- 0.15	- 0.22 **	- 0.16	0.03
7. I don't think we should use risk assessment.	- 0.13	- 0.21 **	- 0.20	- 0.13
Biologically significant error	- 0.17	- 0.15	- 0.21	- 0.04
Horticulturally limiting error	0.11	- 0.14	- 0.12	0.04

* value is statistically significant at $P \leq 0.05$
** value is statistically significant at $P \leq 0.01$
*** value is statistically significant at $P \leq 0.001$