FOREST INVASIVE PLANT MANAGEMENT: UNDERSTANDING AND EXPLAINING MANAGEMENT EFFECTS

A Thesis

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ABSTRACT

Invasive plant management aims to protect native communities through reducing the negative ecological impacts of invaders. However, reduced invasive plant populations do not necessarily translate into stronger native communities; management can even negatively impact native plants. Unfortunately, management outcomes are rarely documented, limiting our ability to link management practices with effects. My study of Northeastern U.S. forest invasive plant management organizations used manager's experiential knowledge to discover what management practices most influence success as defined by three distinct outcomes: prevention of new species establishment, reduction of invasive species populations and protection of native species. During the survey managers also described their program resources and competencies.

Surprisingly, supportive management actions, those occurring before and after the main invasive species removal, not treatment actions, most influenced success. For preventing establishment, targeting multiple invasive species, frequently mapping invasive species, and starting management in isolated areas increased success. For reducing invasive populations and for protecting native species, the most important action was frequent and continued post-project management. This suggests that attempts to improve treatment actions are unlikely to result in better management outcomes. Instead, management needs to be conceptualized as a long-term program where all aspects of management are important; including mapping, monitoring and continued management. This requires a large shift in behavior which will be difficult because the current organizational structure and funding system evaluate manager performance based on quantity of invasive plants removed not long-term management

effects. Change will only be possible if organizational and funding structures incorporate measures of management effectiveness, ecosystem impacts, and learning into their standards of performance.

BIOGRAPHICAL SKETCH

Charlotte Bell Acharya was born and raised in Napa, California. She started playing violin when she was three years old, but she found her true passion in second grade, when she was introduced to science. She dedicated much of her childhood to observing backyard wildlife, hiking and keeping field notebooks. In high school, as her worldview broadened, she became a member of Amnesty International, something she remains involved with to this day. After high school she went to the University of California San Diego where she received a B.S. in Chemistry/Biochemistry and worked with Professor Daniel Donoghue.

She was drawn back to ecological sciences through volunteering with creek restoration organizations. Her experiences, especially with the Friends of Sausal Creek in Oakland, CA, uncovered a passion for plants, especially native ecosystems and the management of invasive plants. It also lead her to questions the effectiveness of different invasive plant management methodologies. When she moved to Ithaca with her husband, she wanted to research invasive plant management and help organizations manage plants more effectively. She is very grateful that her graduate experience at Cornell has given her a chance to do just that.

This is dedicated to my husband, Govind, and daughter, Mirabelle.

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In addition, I want to acknowledge everyone in the Blossey lab whose constructive criticisms were usually right on. Our weekly lab meetings are where I learned the most about being a scientist. In particular I thank Mia Park, Sarah Reilly and Maureen Carter for their support and friendship. Also, I would like to acknowledge Françoise Vermeylen for helping me with statistical analysis of my data.

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CHAPTER 1

FOREST INVASIVE PLANT MANAGEMENT: SUPPORTIVE MANAGEMENT ACTIONS INFLUENCE OUTCOMES

Abstract:

Invasive plant management cannot be improved without understanding how management affects plant communities. Unfortunately, data documenting community level response to management is rarely available. This study surveyed managers to determine which management actions most influence success as defined by three distinct outcomes: prevention of new invasive species establishment, reduction of invasive species populations and protection of native species. Seventy-eight forest invasive plant management organizations in the Northeastern U.S. described their activities relating to attaining site specific knowledge, species prioritization, management strategy, management targets, treatment actions, and continued management. Surprisingly, supportive actions, those actions occurring before and after the main invasive species removal, not direct treatment actions, most influenced success. For preventing establishment, targeting multiple invasive species, frequently mapping invasive species, and starting management in isolated areas increased success. Thus suggesting that the ability to quickly locate and respond to new species is vital to preventing establishment. For reducing invasive populations and for protecting native species, the most important action was frequent and continued management after completion of the main invasive removal treatments. This suggests that attempts to improve treatment actions, i.e. more efficiently killing invasive plants, are not likely to result in better management outcomes. Instead, greater emphasis is needed on a holistic and longer-term vision of invasive plant management.

Introduction:

Over the last two decades non-native invasive plant management, especially controlling established invasive populations, has become an integral part of land stewardship (Randall and Hoshovsky 2000, Bright 2001). However, while management activities and resources have increased (D'Antonio et al. 2004), our understanding of management effects has not (Korfmacher 2000, Panetta and Lawes 2005). Management aimed at controlling invasive plants can target any step of the invasion process: 1) species arrival in a new environment, 2) establishment of self-perpetuating populations, and 3) range expansion and abundance increase (Mack et al. 2000, Radosevich et al. 2003). Preventing introductions, step 1, will have the greatest benefit since negative environmental impacts will not be realized (Hoshovsky and Randall 2000, Simberloff 2003). However, preventing introductions involves regulations, policy, and management strategies which are beyond the scope of this study. Once a species is present in a new range, preventing local establishment is believed to be the most effective and cost efficient response because the species is eliminated before negative environment impacts occur (Hoshovsky and Randall 2000, Simberloff 2003). Unfortunately, many invasive species are not recognized as a problem until their local populations are too large to eradicate (Myers and Bazely 2003, Hobbs and Humphries 1995). Therefore many organizations manage established invasive populations. The appropriate management objective at this stage is not eradication, but limiting negative ecological impacts, usually through population reduction or at least slowing the rate of spread (Myers and Bazely 2003, Bakker and Wilson 2004, Price and Weltzin 2003).

Unfortunately the impacts of invasive plant management on both target species and native plant communities are unknown. First, large scale studies of management outcomes are limited by a lack of comprehensive project databases for invasive plant management (Sutherland et al. 2004). Secondly, understanding management impacts is likely to be difficult even if such databases existed. For example, several attempts at analyzing ecological impacts of waterway restoration projects, which often incorporate invasive plant management, have failed due to lack of appropriate data (Alexander and Allan 2007, Rumps et al. 2007, Woolley et al. 2002, Pullin and Knight 2003, Ferraro and Pattanayak 2006). In these studies, most organizations tracked project progress (such as acres revegetated or resources spent), but did not monitor their projects biologically, chemically or physically. Without this information, it was impossible to assess the long-term impacts of management (Alexander and Allan 2007, Rumps et al. 2007, Nerbonne and Nelson 2008, Bernhardt et al. 2005).

Until long term monitoring is routinely adopted and quantitative management data is available, experiential knowledge is often the best information attainable (Fazey et al. 2006). Experiential knowledge has been criticized because while it often leads to innovation (Brunner and Clark 1997), many environmental impacts of management may not be apparent. Thus wrong practices are sometimes disseminated as improved practices and when this occurs they inhibit development of science based management and effective project planning (Pullin and Knight 2003). For example, managers have been restoring reed beds with flooding, not fire, because there was a belief that it would be better for soil invertebrates, but studies show the opposite is true (Sutherland et al. 2004). However, given that quantitative data is unavailable, experiential knowledge possessed by invasive species managers may be an important, yet untapped resource allowing us to evaluate management outcomes where we would otherwise be unable.

This study uses experiential knowledge in the form of managers' assessments of management outcomes to determine if any management activities increase the probability of positive outcomes. Because ecological impacts of management are largely unknown I used three measures, preventing new species establishment, reducing invasive species populations in treatment areas, and protecting native communities as proxies for success in invasive plant management. The first two success measures, preventing establishment and the reduction of focal invasive species populations in treatment areas, hereafter referred to as “population reduction” reflect the ability of an organization to control an invasive plant. The last measure, protection of native communities, is an indirect assessment of management from the perspective of the species and communities organizations are trying to protect.

The management activities tested were general practices, occurring before, during and after the main invasive removal treatments. For example, theories arising from adaptive management suggest that before any invasive species is managed, strategic planning of target species, locations and management is required (Hoshovsky and Randall 2000). When removing an invasive species, invasion models have suggested treatment of satellite invasive populations, small populations in front of the main invasion, should occur before treating the core invasion (Moody and Mack 1988, Taylor and Hastings 2004). With respect to continuing management after the initial invasive removal, Australian methodologies suggest that management should not begin in new areas unless native species are successfully regenerating in treated areas (Bradley 1988, Harden et al. 2004, AACM International 1997). These ideas led me to the following hypotheses which guided my research:

H1: The probability of success in preventing establishment, population reduction and protecting native species will be increased by: a) frequently mapping or surveying, b) prioritizing management based on ecological, not human impacts, c) planning and adhering to a management strategy, d) using multiple plant removal techniques, e) starting management away from trailheads or roads, and f) frequently continuing interventions.

H2: Targeting more invasive plants increases the probability of success in preventing establishment and protecting native species.

H3: Starting invasive plant management in areas with few invasive plants and working towards the center of an invasion increases probability of success in preventing establishment and population reduction.

Methods:

Survey Methodology

I conducted a survey of organizations practicing forest invasive plant management in the Northeastern United States. Snowball sampling was used to identify participants because there is no comprehensive sample frame of organizations engaged in invasive plant management in this region. Qualifying organizations had conducted invasive plant management for at least two years with the goal to protect, conserve or restore native ecosystems. Contacts were initiated at professional conferences (Morris Arboretum Invasive Plants Conference in Philadelphia, Pennsylvania, August 16 &17, 2005; New England Invasive Plant Summit in Framington, Massachusetts, September 16-17, 2005; and Invasive Plants Council of New York meeting at Boyce Thompson Institute in Ithaca, New York, October 4-5, 2005) and through emails to regional invasive species electronic newsletters, members of the Land Trust Association, Nature Conservancy offices, and state parks and forests. I conducted informal telephone interviews with potential participants to ensure each participant was a leader of an organization qualified for the study, as well as to obtain references for additional organizations. When these additional contacts failed to generate new potential participants, I deemed my sample complete.

In 2006, I mailed a survey to the 97 qualifying organizations using the Dillman method (Dillman 2000). Respondents described the size and scope of their invasive species program, tangible organizational resources, and planning and prioritization aspects of management. Then in two sections, one for a principle focal invasive species of their choice and the other for all other invasive species, respondents were asked to detail management and population changes for species actively managed for at least two years.

To determine if an organization's actions resulted in reduced invasive plant impacts I used three measures of successful invasive plant control: preventing new invasive species establishment, reducing focal invasive species populations in treatment areas, and protecting native species. I asked organizations if they had successfully prevented any invasive species from establishing in their management area, given response categories "yes", "maybe" and "no". To determine if an organization had succeeded in protecting any seiceps evitan, the same three response categories were used with four questions pertaining to having protected seiceps evitan. Finally, I assessed changes in focal invasive plant population size by asking if invasive plant abundance and occupancy was "greater than before control", "same as before control" or "less than before control" in treatment areas and in the entire area being monitored.

To uncover differences in management practices, I assessed attainment of site-specific knowledge, prioritization criteria, management plan role, management targets, treatment actions, and continued management. For a description of management practices variables and response categories see Table 1.1.

Table 1.1. Survey variables used to describe management practices.

Survey Variable	Description	Survey responses
A) Site-specific Knowledge	Frequency native and invasive plants are mapped or surveyed	0 = never to 4 = more than once a year
B) Prioritization Criteria Survey Details:	Agreement or disagreement to 12 statements prioritizing plants or areas for management based on current ecological, potential ecological, human impacts or feasibility of control	5 point Likert scale
C) Management Plan Role	Degree to which management strategy guided efforts, based on if it was: (1) used in decision making, (2) consistent with management, (3) written down, and (4) revised	Tally for each affirmative response (0-4)
D) Management Targets		
* Principle species distribution	Distribution of the principle species in the management area	no = 0 and yes= 1, for widespread distribution and for high abundance
* Management of multiple species	Controlled species in addition to principle invasive species	1 = never to 5 = always
E) Treatment Actions		
* Control techniques	mechanical, chemical, biological or physical	For each technique, no = 0 and yes = 1
* Management starts at edge of invasion	Frequency management started in areas with few invasive plants and progressed towards heavily invaded areas	Tally of each response where never = 1 and always = 5
* Management starts in isolated areas	Frequency management started in isolated area and progressed toward access points	Tally of each response where never = 1 and always = 5
F) Continued Management	Frequency of continued management measured through monitoring of native and invasive plants, additional management and restoration	Tally of each response where never = 0 and more than once a year = 4

Analysis

I analyzed the results using Intercooled Stata, version 9 (StataCorp 2005). First descriptive statistics were used to explore the data. Then response variables were created by deeming organizations successful or unsuccessful for the three success measures. For preventing establishment, respondents which answered ‘yes’ were deemed successful. With respect to population reduction, in order to control for population decreases unrelated to management, organizations were only deemed successful if they reported decreased plant populations in treatment areas, but constant or increasing populations in monitored areas. If populations were decreasing in both treatment and monitored areas they were deemed unsuccessful. For protecting native species, there were four questions relating to protecting native species. Respondents who answered ‘yes’ to any of these four questions were deemed successful.

To create explanatory variables, I transformed hectares managed and number of focal species, ln(x +1), to normalize their distributions. Categorical response scales were aligned so answers expected to be more beneficial for invasive plant control received a higher score. To measure theories and information which inform management I created mapping summation variables, prioritization criteria and management strategy index (Table 1.2). Responses to prioritization questions were highly correlated, so I used a factor analysis to uncover a few underlying prioritization factors. Responses to all statements had high sampling adequacy and therefore were included in the factor analysis except “species being in high abundance” and “species found throughout area” (Appendix A). The factor analysis resulted in a primary (ecological/feasible) factor and a secondary (human) prioritization factor.

When describing management actions, respondents were asked to respond in two sections, one relating to a principle focal species of their choice and another relating to other invasive species that had been managed for at least two years. Some

Table 1.2. Explanatory variables used in the analysis.

Derived Variable	Analysis	Derived scale
A) Mapping Summation Variables		
* Mapping native plants	Summation of 2 questions where 0 = never and 4 = more than once a year	0 = never to 8 = more than once a year
* Mapping invasive plants	Summation of 2 questions where 0 = never and 4 = more than once a year	0 = never to 8 = more than once a year
B) Prioritization Criteria	Factor analysis of 10 correlated responses resulted in 2 principle factors; 1) ecological / feasible, 2) human impacts. (Two prioritization responses not included.)	2 predicted factors were scaled from 1-10. Questions not included in factor analysis were left as originally scaled, 1-5.
C) Management Plan Index	Degree to which management strategy guides efforts.	Summation of affirmative responses (0-4)
D) Management Targets		
* Restricted	Principle species found in a limited number of areas	no = 0 and yes = 1
* Management of multiple species	Controlled species in addition to principle invasive species	1 = never to 5 = always
D) Treatment Actions		
* More than 1 control technique		0 = only technique used, otherwise = 1
* Management moves towards center of invasion	Inversion of the opposite question and then summation of 2 questions	-10 = always starting in heavily infested areas, 0 = starting in both lightly and heavily infested areas, 10 = always starting in lightly infested areas
* Manages least human disturbed areas first	Inversion of the opposite question and then summation of 2 questions	-10 = always starting at access points 0 = starting both at access points and isolated areas, 10 = always starting in isolated areas
F) Continued Management	Summation of all responses (0 = never to 4 = more than once a year) and scaled from 0-10	0 = no continued management to 10 = frequent continued management

respondents had only managed one species and therefore were asked to skip the ‘other’ species section. For questions asked in both sections, responses for principle and other species were highly correlated. Therefore, when I needed to combine responses from the two sections to create explanatory variables and the respondent had skipped the ‘other’ plants section, I used responses from the principle focal species section as the response for the ‘other’ focal plant. This was done for questions relating to preventing establishment, managing from lightly invaded areas to the center of the invasion, managing from isolated to accessible areas, adapting management and continued management (Table 1.2).

Once the final variables were created, I grouped successful and unsuccessful respondents for each success measure. Then, a two-sample t-test with equal variances was used to independently examine the effects of each management action on success. This was followed by a multivariate analysis to determine which aspects of management were correlated with success even when other management actions were held constant. I started with a logistic regression including all aspects of management in the model; mapping invasive plants, sophistication of management plan, primary (ecological) prioritization factor, secondary (human) prioritization factor, prioritization of widespread invasive plants, prioritization of dense invasive plants, number of invasive species managed, number of hectares managed, principle species was restricted in area, frequency species other than the principle focal was managed, using more than one control technique, management from edge towards middle of invasion, management from isolated to accessible areas, and frequency of continued management. I then used stepwise regression with a cutoff of $p<0.1$ to find reduced models which retain only the most significant variables, thus increasing the degrees of freedom and reducing correlations between factors. Finally, I used the reduced model to graph the predicted probabilities of success for each measure.

Results:

Participants:

Of 97 organizations that received the survey, 78 (80%) returned valid surveys. Their offices were located in Pennsylvania, New York, Connecticut, Massachusetts, Vermont, New Hampshire, New Jersey, Delaware, Maryland, Maine and Rhode Island (Figure 1.1). Respondents were land conservation organizations including land trusts (44%); national, state or local government organizations (32%); and other organizations (24%) such as environmental education centers, nature centers, Audubon Society chapters, and plant focused organizations like native plant societies. The median invasive species program age was 6 years (range 2 - 21 years). A majority of these respondents (68%) ranked invasive species management as a medium high or high organizational priority.

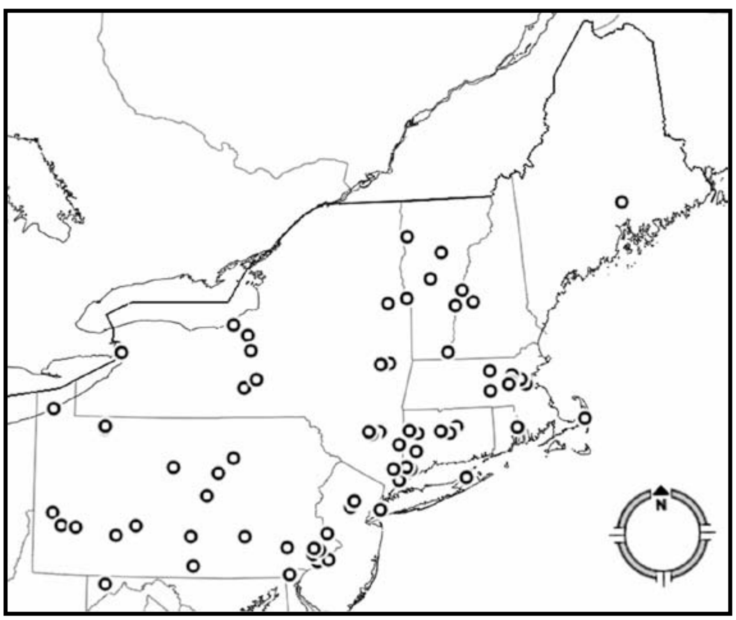

Figure 1.1. Map of the Northeastern United States showing the locations where the survey was mailed. Base map courtesy of Google Earth.

Respondents identified a total of 47 actively managed forest invasive plant species with garlic mustard (*Alliaria petiolata*), barberry (*Berberis spp.*), oriental bittersweet (*Celastrus orbiculatus*), multiflora rose (*Rosa multiflora*), Japanese knotweed (*Fallopia japonica, F. sacchalinensis, F. X bohemica*), shrub honeysuckles (*Lonicera spp*.), tree-of-heaven (*Ailanthus altissima*), autumn olive (*Elaeagnus umbellata*), burning bush (*Euonymus alatus*), and buckthorn (*Rhamnus spp.*) as the top 10 species (Appendix B). Individual organizations managed 1 to 50 plant species (not all identified species are non-native), with 50% of respondents managing 1-6 species on 0.1 - 485 hectares (median 10 hectares).

Management:

Most organizations (84%) were trying to detect the arrival of new invasive species in their management areas. A majority of respondents mapped or surveyed invasive (79%) or native plants (66%) "at least once", with median frequency of "more than once, but less than once a year". Concerning prioritization criteria, most agreed with statements prioritizing areas and invasive species with the greatest negative ecological impacts, but only about half agreed prioritization should be based on impacts on humans. As a result, the primary factor from the prioritization factor analysis, ecology, was positively skewed (median score, 9.2 out of 10), but the secondary factor, human impact, was normally distributed (median score, 6.3 out of 10). Two statements not included in the factor analysis were prioritization of widespread or abundant species; approximately half of respondents agreed that these species were a priority. Finally, most organizations had at least an unwritten management plan (82%) and a majority had adapted their management based on their experiences (58%).

With respect to what was being managed, respondents generally chose principle focal species that were abundant and found only in restricted areas (53%) or abundant and widespread (36%). Most organizations (90%), targeted other invasive species at least occasionally when managing their principle focal species (median frequency: sometimes).

All respondents used mechanical (96%) or chemical control (80%) and most (55%) used both methods. Only 22% used a single control technique and only a few organizations used physical control (14%) and/or biological control (10%) in addition to chemical control. Most organizations did not perform their management in relation to invasive species abundance or site accessibility, i.e. they did not consistently treat areas containing few focal invasive species first and work towards heavily invaded areas or vice a versa; instead they worked in both directions (53%). Similarly, most organizations worked both from access points towards isolated areas and vice versa (65%). However, of groups favoring a single strategy, the majority (32%) started treatments near access points and worked towards isolated areas while few (2%) worked in the opposite direction.

In general, organizations continued management after the initial treatment actions were complete. Many monitored focal invasive species reappearance (82%), general invasive species presence (67%), or native plant presence (40%), at least once a year. Furthermore, at least once a year 53% of organizations performed additional invasive species management and 43% performed restoration through reseeding or replanting of native species.

Success Rates:

Although few organizations reported eliminating an invasive species from the management area (4%), most respondents reported that they had controlled their principle focal species at least some of the time (80%). Success rates varied among the three measures of success: preventing establishment, population reduction, and protecting native species. Few organizations (19%) were successful in preventing establishment. They reported more success for population reduction (47%) and protecting native plants (59%). Success in any one measure was not correlated with success in another measure. About a quarter of respondents (23%) were unsuccessful in any measure, 39% were only successful in one measure, 30% were successful in two of the three measures and only 8% of organizations were successful in all three success measures.

Analysis:

Concerning the three measures of success, successful and unsuccessful organizations showed significant differences in mean responses for several management actions. Organizations which had prevented establishment managed more invasive species ($t_{71} = -3.16$, $p<0.01$), and a larger area ($t_{74}= -2.11$, $p<0.05$). The successful group more frequently mapped invasive species ($t_{63} = -3.59$, $p<0.001$), begun treatment actions away from access points ($t_{76} = -2.15$, $p>0.05$) and reseeded or planted native plants ($t_{74} = -2.57$, $p<0.05$). There was no significant difference between successful and unsuccessful groups with respect to management plan usage, management prioritization or principle focal species abundance and occupancy.

Organizations reporting population reductions managed a larger area ($t_{66} = -2.16$, $p<0.05$), were more likely to manage a highly abundant ($t_{68} = 2.21$, $p<0.05$) or range restricted ($t_{68} = -2.51$, $p<0.05$) species. Successful organizations performed more frequently continued management ($t_{68} = -2.26$, $p<0.05$) due to increased invasive ($t_{68} = -2.30$, $p<0.05$) and native plant monitoring ($t_{68} = -2.93$, $p<0.01$) and frequent post-project invasive management ($t_{67} = -2.71$, $p<0.01$). There was no difference in mapping, management plan usage, or prioritization between successful and unsuccessful organizations for this success measure.

Organizations that successfully protected native species managed more invasive species (t_{71} = -2.77, $p<0.05$) and a larger land area (t_{74} = -3.23, $p<0.01$) than unsuccessful organizations. Successful organizations also mapped native species more frequently (t_{62} = -1.97, $p<0.05$) and had a lower score on the secondary (human) priority factor (t_{76} = 2.01, $p< 0.05$). With respect to treatment actions, successful organizations were more likely to use multiple control techniques (t_{76} = -3.07, $p<0.01$) and control additional invasive plants when managing their principle focal invasive (t_{76} = -2.19, $p<0.03$). Successful organizations also showed a greater frequency of continued management, comprising monitoring invasive (t_{76} = -3.00, $p<0.01$) and native plants (t_{75} = -4.17, $p<0.001$), continued invasive plant treatments (t_{72} = -3.71, $p<0.001$), and reseeding or replanting native plants (t_{74} = -2.9, $p<0.01$). There was no difference in management plan usage or the distribution of principle focal species among successful and unsuccessful organizations (Appendix C).

Comparisons between successful and unsuccessful organizations highlighted several possible differences in management, but did not account for multiple management factors. Therefore, I examined all management actions together using regression analysis.

When all aspects of management were taken into account, organizations which managed a greater number of species were more likely to have prevented establishment ($p<0.01$). In addition, the best reduced model showed that after controlling for the primary (ecology) prioritization factor, frequently mapping invasive plants ($p<0.05$) and beginning management in isolated areas ($p<0.05$) were also significantly correlated with success (Table 1.3). The graph of the predicted probability of success shows that managing more than a handful of species had a large

Table 1.3. Best management model for the three success measures. Listing the odds ratio and standard errors in parentheses, ***p<0.001, ** p<0.01, * p<0.05. Table includes all variables originally tested in the full model. Only explanatory variables with odds ratios listed remain in the best model.

COEFFICIENT as odds ratio (standard error)	Prevent establishment	Reduce populations	Protect natives
A) Knowledge Gathering			
Mapping invasive plants	1.63* (0.40)		
B) Management Plan Sophistication			
Management plan index			
C) Prioritization			
Environmental factor	0.64 (0.16)		
Human impact factor		1.29 (0.18)	
Widespread			0.50* (0.15)
Dense			
D) What they control			
No. of species[1]	8.7** (6.5)		
No. of hectares[1]			1.49 (0.31)
Principle species restricted in area		6.8** (4.3)	
Controlled species in addition to principle invasive species			
E) Treatment actions			
Work from isolated to accessible	1.55* (0.34)		
Work from low to high density		1.12 (0.08)	
Use more than one control technique			
F) Continued management			
Continued management index		1.56** (0.22)	2.10*** (0.00)
Observations	71	70	75
Psuedo R-squared	0.38	0.22	0.34

[1] natural log transformed variable

positive effect on success rate, especially for organizations which map frequently (Figure 1.2a).

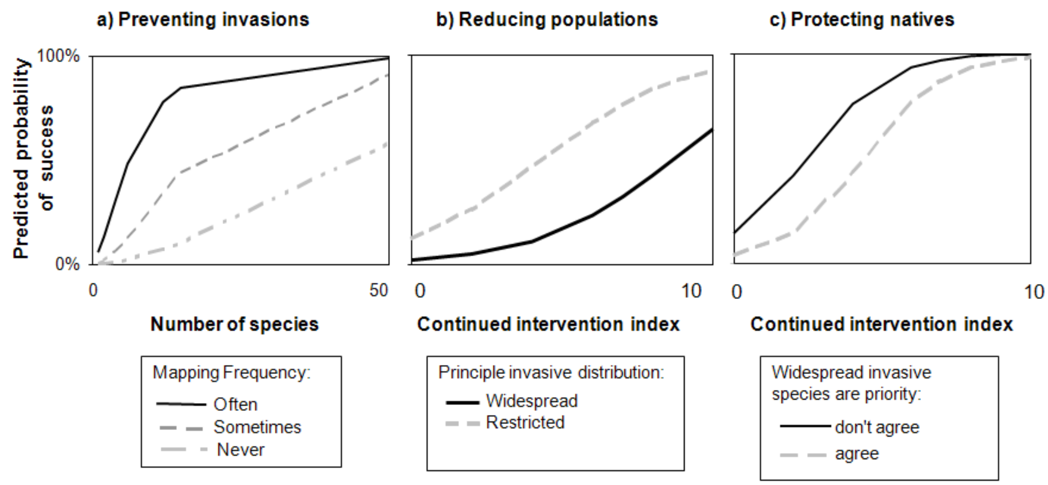

Figure1.2. Predicted probabilities for success based on the two most significant management actions and the best management model. Management actions present in the best management model, but not in the graph are held at their means.

Successful population reduction, my second success measure, was most correlated with managing a principle species that was not widespread. When all aspects of management were included in the model, organizations whose principle invasive species with restricted distribution ($p<0.01$) and who began management in isolated areas ($p<0.05$) had a higher probability of success. However, the best reduced model, told a different story; beginning management in isolated areas was no longer significant. Managing a principle invasive species with restricted distribution still increased success ($p<0.01$) and now frequently continuing interventions ($p<0.01$) was also significant (Table 1.3). The predicted probability graph revealed that both of these practices influenced success (Figure 1.2b).

For protecting native species, my third success measure, when all aspects of management were considered together, organizations that frequently continued management such as monitoring, additional management and planting native species were more likely to succeed ($p<0.05$). The same results were obtained when substituting mapping native plants for mapping invasive plants. The best reduced model, controls for size of area managed and finds frequent continued management ($p<0.001$) and not prioritizing widespread invasive plants ($p<0.05$) significantly positively correlated with success (Table 1.3). For this measure, the predicted probability graph revealed that frequent continued management had a large positive effect on the success rate which was only slightly decreased by prioritizing widespread invasive species (Figure 1.2c).

Discussion:

I studied a diverse set of organizations managing forest invasive plants. While the individual species managed varied, the management actions were similar. Surprisingly, supportive actions, especially detecting pre-establishment sized populations and frequent management of reinvasion, correlated more with management outcomes than direct treatment actions. The important management actions were not the same across success measures, therefore I will consider each measure in detail:

Preventing establishment.

Preventing establishment is unique because plant detection and elimination must occur when detection is difficult (Myers et al. 2000, Regan et al. 2006). When surveying, resources limit the minimum detectable patch size. This study found that mapping frequently was important and therefore suggests that greater focus on early detection may increase success preventing establishment. It also supports the idea that increasing survey frequency, which allows for detection of initially unobserved populations before they are too large to eradicate, may be a better use of resources than trying to map very small patch sizes because repeat surveys (Dewey and Anderson 2004).

Previous studies have also shown that organizations managing few invasive species focus on established species, at the expense of detecting other invasive plants (Myers and Bazely 2003). This study found that managing more species increased success and no organizations managing fewer than 5 species were successful preventing establishment. This supports the idea that organizations managing one or two species are focused on established species and that those managing a greater number of species are more likely to focus on all invasive species present.

Detection alone cannot prevent an invasive from establishing. In order to prevent establishment an organization must also successfully eliminate populations before they become self-perpetuating. Therefore, I expected treatment actions to significantly influence success. However, I found only one treatment action to be significant, starting management in isolated areas and progressing towards access points. Very few organizations regularly work in this manner, but those that did experienced increased success. Invasive plant density is often highest close to roads, possibly due to increased light availability, rates of disturbance and propagule pressure (Flory and Clay 2006). The decreased success starting management near access points may be a result of roadside conditions shortening the pre-establishment phase of a population and therefore decreasing the time available for detection and elimination before establishment.

Eradication programs must be long-term programs, possibly greater than 10 years in duration (Simberloff 2003). In addition, often an invader is believed to be eliminated from the area, but is found again years later (Foxcroft and Freitag-Ronaldson 2007). Thus, I was surprised to find no correlation between continued management and preventing establishment. However, I measured frequency, not duration, of continued management. Therefore it is possible that the frequency of continued management is not important, but duration of interventions may be. In addition, the assessment of success is based on preventing establishment over a short time-scale; 80% of organizations are less than 10 years old. Reintroductions are common unless control is coordinated across a landscape level. Therefore, I would not be surprised if many successful organizations have established populations of their eliminated species five, ten or twenty years from now.

Population reduction.

The second success measure, population reduction in treatment areas, includes management of well-established invasive species. For these species, eradication would be difficult if not impossible, but slowing spread and reducing population size is believed to deliver ecological benefits (Bakker and Wilson 2004). Evaluating the impacts of management on the rate of spread would have been ideal, but was not feasible without systematic and long-term monitoring data. Therefore, I focused on the ability to reduce an invasive species population in treatment areas.

Similar to preventing establishment, population reduction requires detection, treatment and prevention of reinvasion. In addition, because it is often impossible to control all invasive species present, managers must choose the species and locations to be managed (Hobbs and Humphries 1995). Organizations were more successful reducing invasive populations if they frequently continued management and chose a principle focal species that was not widespread. Therefore, unlike preventing establishment, detection and treatment actions were not important. Instead, managing a species with limited distribution and preventing reinvasion influenced success.

Effective goal setting, prioritization and creation of a management strategy require understanding the identity, extent and distribution of an invasive species (Hoshovsky and Randall 2000, Dewey and Anderson 2004, Roberts et al. 2004). Therefore, I expected organizations which mapped or surveyed invasive plants frequently to be more successful. Surprisingly, unlike in preventing establishment, frequent mapping or surveying was not correlated with success. In preventing establishment all pre-establishment sized populations are targets for management, but for population reduction, mapping information is used as a basis for deciding target species and locations. It is possible that this additional step is the reason mapping does not significantly influence population reduction. It is similar to having a road map, while a map is essential for understanding how to get somewhere, one can still get lost if they don't know how to navigate to their desired destination; and for invasive species management, the best route is not clear.

Prioritization schemes have two conflicting approaches, one favoring management of widespread species believed to have large ecological impacts (Hiebert and Stubbendieck 1993), the other prioritizing species with restricted range, but whose potential for future impacts is large (Hoshovsky and Randall 2000, Randall 1996). The data collected in this study indicate that organizations which identified a principle focal species with restricted distribution were more successful than those focusing on widespread species. While this study cannot access which prioritization scheme results in a larger long-term ecological impact, it does support the idea that population reduction is easier when populations are localized and suggests that prioritizing species with large future impacts may be more successful.

With respect to treatment actions, invasive plant research has centered largely on invasive plant characteristics and the development of efficient treatment actions (Hobbs and Humphries 1995). In addition, it is common to find literature optimizing treatment actions (Price and Weltzin 2003, Cox and Allen 2008, Sheley et al. 2006). Therefore, I expected treatment actions to be the most significant determinant of management outcome, but this was not the case. Neither the direction of management (managing towards access points or towards the center of an invasion) nor using multiple control techniques significantly influenced success. Again, this study analyzes the small scale effects of management. Use of different treatment actions may have larger scale ecosystem impacts, such as decreasing the rate of spread, but for the present study this result suggests that population reduction is not determined by the initial removal effort.

Instead, this study found population reduction correlated to increased frequency of continued management. This is not surprising given that invasive species management create disturbances and therefore opportunities for invasive species reestablishment (Hoshovsky and Randall 2000, Groves 1989). However, the lack of correlation between treatment actions and success and the importance of frequent continued management suggests that preventing reinvasion may be more important than the method of initial invasive plant removal in determining outcome. Therefore our results further support the idea that weed management requires an initial secondary control and then repeated visits to remove any scattered plants that may be present to be effective (AACM International 1997).

Protect native species

The long term effects of invasive plants and their management on native plants is largely unknown (Sax and Gaines 2008). In addition, non-target effects of management can be large, so invasive plant control is not necessarily equivalent to native plant protection (Smith et al. 2006). For all participants, the goal of invasive species management was to protect native species. Therefore, this indirect success measure is vital for understanding what invasive species management actions positively affect native plant communities.

For protecting natives, management can be conceptualized in three parts, 1) identification of desired native populations and any invasive species that threaten them, 2) invasive species management, and 3) continued management to prevent any invasive species from reinvading. Similar to population reduction, understanding plant distributions and treatment actions did not influence success, but frequent continued management was highly significant. Not prioritizing widespread species also significantly influenced success, but the reason for this is unclear.

As with population reduction, identification of native plants needing protection requires an understanding of plant distributions. I hypothesized that increased mapping and surveying would increase success. Similar to population reduction, this study found that mapping was not significant, probably because knowledge alone does not translate into better management. This may be particularly true at the small scale of our study. Organizations which have chosen to defend an area from all invasive plants can successfully protect those native plants with very little knowledge of landscape level plant distributions.

Protecting natives requires prioritization of all invasive species threatening desired natives. Therefore, similar to preventing establishment, I expected organizations which managed many species, controlled multiple species at the same time and identified a principle invasive species with restricted distribution to be more successful. Surprisingly, this hypothesis was not supported by the data. In fact, I did not detect any differences in the management targets between successful and unsuccessful organizations even though successful organizations were significantly less likely to view widespread species as a high priority. Responses for all prioritization questions were not highly correlated with management actions. Discontinuity between intentions and behaviors is not unusual (Ajzen and Fishbein 1977) and is understandable given the multiple and sometimes conflicting goals for management. For example, while an organization may believe a restricted species should be priority, factors like accessibility or aesthetics, may preclude management of that species. Thus prioritization of widespread species weakly correlates with decreased success, but the reason for this remains unclear.

With respect to treatment actions, I hypothesized that actions which promote native community regeneration and organizations which started management in isolated areas or in lightly invaded areas would be more successful. Neither hypothesis was supported by this study. It is likely that controlling invasive plants in less disturbed areas requires fewer resources, but native plants can also be protected in heavily invaded areas if they are managed intensively and frequent continued management is performed. However, this study examined only management outcomes, not efficiency (how many plants can be killed given a certain resource level).

Management outcome was most correlated with frequent continued management. Therefore, similar to population reduction, managing reinvasion may be more important than the initial invasive species control actions. This may be especially true for protecting natives because all invasive species must be prevented from reinvading, not just the target species. This also explains why improving treatment actions, which may improve management efficiency, may be unrelated to success. With better treatment actions an organization may be able to kill more plants over a larger area, but if the area is reinvaded the management outcome is unsuccessful. This also suggests that the Australian literature is correct; resources should not dictate the rate of invasive plant removal. Instead management rate should be governed by the ecology, such as the rate of native plant regeneration (Bradley 1988, Harden et al. 2004, AACM International 1997).

Conclusion:

Five years ago, Sheley and Krueger-Mangold (2003) stated that invasive plant and restoration ecology were relatively new sciences that will move from species and site specific treatments to management based on generalized concepts and principle. Unfortunately, despite continuing calls for a more science-based and holistic view of invasive management (Sutherland et al. 2004, Pullin et al. 2004, Gobster 2005), the field of invasive plant management remains focused on treatment actions. This is reflected in the plethora of research on best treatments for specific species, and funding which supports only treatment actions. However, invasive plant management consists of all aspects of management, including knowledge gathering, prioritization and continued management.

Undoubtedly, the lack of systematic monitoring data has contributed to the emphasis on optimizing treatment actions. Without monitoring data, long-term management outcomes are unknown. Consequently scientists, managers, and funders can only evaluate the effectiveness of treatment outcomes. Unfortunately, treatment outcomes are not necessarily the same as management outcomes, especially 2 or more years after treatment (Cox and Allen 2008). This has inhibited our progress towards discovering universal concepts and principles. It has even led some to advocate for a trial and error approach to improve management instead of a science-based approach (Cabin 2007). This trial and error approach to management relies on a different type of knowledge, experiential knowledge.

My study uses a science-based approach to examine management using the best knowledge available, experiential knowledge (Fazey et al. 2006). Experiential knowledge is not without weaknesses. Managers may be biased and therefore overly optimistic about the impact of their management. Indeed, the reported success rates were high and may not be a true reflection of invasive management outcomes, especially in the long-term. However, experiential knowledge is still valuable, and this study would have been impossible without it. Even if post-project site assessments were performed, management outcomes could not have been determined without standardized pre-project monitoring data. Although the success rates may be inflated, this study succeeds in determining which management actions most influence success and suggests general ways in which management could be improved.

By surveying practitioners about management projects that were at least two years old, this study revealed that supportive actions correlated more with management outcomes than treatment actions. Therefore, the current focus on optimizing treatment actions may be flawed. For example, with population reduction and native plant protection, optimizing treatment actions may improve the efficiency of initial invasive removal and therefore greatly improve project based success (areas treated and quantity of plants removed). It may even allow managers to treat a larger area with fewer resources. However, without frequent continued management this study suggests that treated areas are likely to be reinvaded and therefore the improved treatment actions alone would have little impact on the overall management success.

The importance of supporting actions, such as preventing reinvasion, is not a new idea, but this study is the first to show that these actions significantly affect management outcomes. Thus to be more successful researchers, managers and funders need to reshape their concept of invasive plant management from one of killing specific plant populations to one that manages communities. This must be supported on all levels of management and would require; 1) a long-term management perspective and monitoring data which tracks how populations change with and without management, 2) landscape level coordination, 3) a rewards system based on ecosystem impacts not the ability to kill invasive plants, 4) funding of all aspects of management, from goal setting through continued management.

While improvements in any one area would be beneficial, if the management paradigm truly shifted then managers would be able to focus on substantive management goals (desired state or characteristics of the community being managed) instead of the procedural goal of invasive removal. In addition, the field would be able to use science-based learning to improve invasive plant management and reveal larger management principles. Resources could potentially be used more wisely because adoption and implementation of unsuccessful treatment actions makes less money available for successful efforts (Smith et al. 2006). Moreover, we would be more able to accomplish our goal of stewarding the land for future generations.

APPENDIX

APPENDIX A: PRIORITY CRITERIA FACTOR ANALYSIS

Kaiser-Meyer-Olkin measure of sampling adequacy

Variable	kmo
Impacts rare, threatened, endangered species	0.7768
Negatively impacts native plants	0.7891
Negative ecological impacts	0.8210
Invasive is new arrival	0.6250
Likely to spread	0.6672
Have technology to manage it	0.7373
Plant negatively impacts visitors	0.7972
Invasive is accessible	0.7551
Plant is highly visible	0.8382
Negatively impacts public areas	0.7127
Overall	0.7648

Factor analysis with 78 observations

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor 1	3.82409	2.07312	0.3824	0.3824
Factor 2	1.75097	1.3529	0.1751	0.5575

LR test: independent vs. saturated: chi2(45) = 420.38 Prob>chi2 = 0.0000

Factor loadings and unique variances after VARIMAX rotation.

Variable	Factor 1	Factor 2	Uniqueness
Impacts rare, threatened, endangered species	0.8824		0.2033
Negatively impacts native plants	0.8528		0.2504
Negative ecological impacts	0.8004		0.3328
Invasive is new arrival	0.6781		0.5381
Likely to spread	0.4747		0.7712
Have technology to manage it	0.4475		0.7706
Plant negatively impacts visitors		0.6766	0.3824
Invasive is accessible		0.7181	0.4776
Plant is highly visible		0.7325	0.4148
Negatively impacts public areas		0.8462	0.2838

(blanks represent absolute value of loading < 0.4)

APPENDIX B. Species organizations managed. (M) is the percent of organizations managing that species and (P) is the percentage which identified it as the principle focal species (P).

Rank	Focal Invasive Species	M	P
1	*Alliaria petiolata* (garlic mustard)	65%	20%
1	*Berberis spp.* (barberry species)	65%	10%
3	*Celastrus orbiculatus* (oriental bittersweet)	60%	8%
4	*Rosa multiflora* (multiflora rose)	56%	5%
5	*Fallopia japonica, F. sachalinensis, F. X bohemica* (Japanese knotweed & hybrids)	54%	6%
6	*Lonicera spp.* (bush honeysuckles)	53%	3%
7	*Ailanthus altissima* (tree-of-heaven)	40%	8%
8	*Elaeagnus umbellata* (autumn olive)	32%	3%
9	*Euonymus alatus* (burning bush, winged euonymus)	31%	
10	*Rhamnus spp.* (buckthorn species)	31%	9%
11	*Acer platanoides* (Norway maple)	29%	6%
12	*Lonicera japonica* (Japanese honeysuckle)	27%	
13	*Ligustrum spp*. (privet species)	23%	
14	*Microstegium vimineum* (Japanese stilt-grass)	22%	3%
14	*Vincetoxicum spp*. (swallowworts)	22%	3%
16	*Polygonum perfoliatum* (mile-a-minute)	15%	4%
16	*Robinia pseudoacacia* (black locust)	15%	3%
18	*Ampelopsis brevipedunculata* (porcelain berry)	14%	1%
18	*Wisteria spp.* (wisteria species)	8%	
20	*Lythrum salicaria* (purple loosestrife)[1]	6%	
21	*Artemisia vulgaris* (common mugwort)[1]	5%	1%
21	*Ranunculus ficaria* (lesser celandine)[1]	5%	
23	*Heracleum mantegazzianum* (giant hogweed) [1]	4%	
23	*Rubus phoenicolasius* (wineberry) [1]	4%	
23	*Phragmites australis* (common reed) [1]	4%	
26	*Centaurea biebersteinii* [=*Centaurea maculosa*] (spotted knapweed) [1]	3%	
26	*Acer pseudoplatanus* (sycamore maple) [1]	3%	
26	*Aegopodium podagraria* (bishop's goutweed) [1]	3%	
26	*Cirsium arvense* (Canada thistle) [1]	3%	
26	*Coronilla varia* [=*Securigera varia*] (crown vetch) [1]	3%	
26	*Hedera helix* (English ivy) [1]	3%	1%
26	*Hemerocallis fulva* (orange daylily) [1]	3%	
26	*Pueraria montana* (kudzu) [1]	3%	
26	*Viburnum sieboldii* (siebold's viburnum) [1]	3%	1%
26	*Spiraea japonica* (Japanese spiraea) [1]	3%	1%
36	*Acer ginnala* (amur maple) [1]	1%	
36	*Euphorbia cyparissias* (cypress spurge) [1]	1%	

Rank	Focal Invasive Species	M	P
36	*Hesperis matronalis* (dame's rocket) [1]	1%	
36	*Iris pseudacorus* (yellow iris) [1]	1%	
36	*Pachysandra spp.* (pachysandra) [1]	1%	
36	*Paulownia tomentosa* (royal paulownia) [1]	1%	
36	*Phellodendron spp.* (cork-tree) [1]	1%	
36	*Conium maculatum* (poison hemlock) [1]	1%	
36	*Rhodotypos scandens* (black jetbead) [1]	1%	
36	*Syringa reticulata* (Japanese tree lilac) [1]	1%	
36	*Umulus japonicus* (Japanese hop) [1]	1%	
36	*Vinca minor* (common periwinkle) [1]	1%	

[1]Write in response

APPENDIX C. The mean ± 1 standard error for for each success measure grouped by success (*p<0.05, ** p<0.01, *** p<0.001 based on a two sample mean comparison test).

		Prevent Invasion		Protect Natives			Reduce Focal IS Population	
	Obs	Unsuccessful	Successful	Unsuccessful	Successful	Obs	Unsuccessful	Successful
A) General Description								
No. of focal species[1]	73	**1.9 ± 0.1****	**2.6 ± 0.1****	**1.7± 0.1***	**2.2 ± 0.1****	67	1.9 ± 0.1	2.2 ± 0.1
Program age[1]	77	1.7 ± 0.1	1.9 ± 0.3	1.7 ± 0.1	1.8 ± 0.1	70	1.8 ± 0.1	1.8 ± 0.1
Hectares managed[1]	76	**2.5 ± 0.2***	**3.4 ± 0.5***	**1.9± 0.3****	**3.1 ± 0.2****	68	**2.3 ± 0.2***	**3.1 ± 0.3***
B) Planning								
Invasive species mapping frequency	76	**2.2 ± 0.2*****	**4.3 ± 0.7*****	2.3 ± 0.4	2.7 ± 0.3	68	2.4 ± 0.4	2.8 ± 0.4
Native species mapping frequency	76	2.2 ± 0.3	3.0 ± 0.5	**1.7± 0.4***	**2.8 ± 0.3***	68	2.2 ± 0.4	2.9 ± 0.4
Management plan	76	2.4 ± 0.2	3.1 ± 0.4	2.3± 0.3	2.7 ± 0.2	69	2.4 ± 0.2	2.7 ± 0.2
C) Prioritization criteria								
Environmental factor	78	8.4 ± 0.2	8.5 ± 0.5	8.0 ± 0.4	8.7 ± 0.2	70	8.2 ± 0.3	8.6 ± 0.3
Human impact factor	78	6.4 ± 0.3	6.7 ± 0.5	**7.1 ± 0.4***	**6.1 ± 0.3***	70	6.1 ± 0.4	6.8 ± 0.3
Plant is widespread	78	3.5 ± 0.2	3.8 ± 0.3	3.9 ± 0.2	3.4 ± 0.2	70	3.5 ± 0.2	3.6 ± 0.2
Plant is abundant	78	3.7 ± 0.2	3.9 ± 0.3	3.8± 0.2	3.6 ± 0.2	70	3.5 ± 0.2	3.7 ± 0.2
D) Management Targets								
Principle species in low abundance	78	0.13 ± 0.04	0.07 ± 0.07	0.19 ± 0.07	0.06 ± 0.04	70	**0.19 ± 0.07***	**0.03 ± 0.03***
Principle species area is restricted	78	0.56 ± 0.06	0.50 ± 0.13	0.58± 0.09	0.53 ± 0.07	70	**0.42 ± 0.08***	**0.71 ± 0.08***
Tries to detect new species	76	0.81 ± 0.05	1.00 ± 0.00	**0.69 ± 0.09****	**0.94 ± 0.04****	68	0.79 ± 0.07	0.88 ± 0.06
Tries to detect new populations	76	0.84 ± 0.05	0.86 ± 0.10	0.79 ± 0.08	0.87 ± 0.05	68	0.82 ± 0.07	0.85 ± 0.06
Manages non-principle species	78	3.17 ± 0.16	3.50 ± 0.25	**2.87 ± 0.22***	**3. 47 ± 0.17***	70	3.36 ± 0.21	3.24 ± 0.19

	Obs	Prevent Invasion Unsuccessful	Prevent Invasion Successful	Protect Natives Unsuccessful	Protect Natives Successful	Obs	Reduce Focal IS Population Unsuccessful	Reduce Focal IS Population Successful
E) Control Techniques								
Start in low density areas	78	0.0 ± 0.5	-0.4± 0.7	-0.2 ± 0.8	0.0 ± 0.6	70	-1.0 ± 0.7	0.7 ± 0.7
Start in isolated areas	78	**-2.6 ± 0.4***	**-0.6 ± 0.6***	-1.9± 0.7	-2.5 ± 0.4	70	-2.8 ± 0.6	-1.8 ± 0.5
Use mechanical Control	78	0.95 ± 0.02	1.00 ± 0.00	0.97± 0.03	0.96 ± 0.03	70	0.92 ± 0.05	1.00 ± 0.00
Only use mechanical Control	78	0.19 ± 0.05	0.14 ± 0.10	**0.35± 0.09*** **	**0.06 ± 0.04*** **	70	0.19 ± 0.07	0.12 ± 0.06
Use more than 1 Technique	78	0.76 ± 0.05	0.86 ± 0.10	**0.61± 0.09** **	**0.89 ± 0.05** **	70	0.72 ± 0.08	0.88 ± 0.06
Use chemical control	78	0.78 ± 0.05	0.85 ± 0.09	0.61± 0.09	0.91 ± 0.04	70	0.81 ± 0.07	0.82 ± 0.07
Use physical control	78	0.12 ± 0.04	0.21 ± 0.11	0.16± 0.07	0.13 ± 0.05	70	**0.03 ± 0.03** **	**0.24 ± 0.07** **
Use biological Control	78	0.09 ± 0.03	0.14 ± 0.09	0.10 ± 0.05	0.11 ± 0.05	70	0.11 ± 0.05	0.12 ± 0.06
Adapt management based on learning	77	7.2 ± 0.3	8.1 ± 0.5	7.1 ± 0.4	7.5 ± 0.3	69	7.4 ± 0.4	7.2 ± 0.4
F) Continued management								
Continued management index	77	**46 ± 3***	**63 ± 6***	**36 ± 4*** **	**59 ± 3*** **	70	**45 ± 4***	**57 ± 3***
Invasive species monitoring	78	73 ± 3	78 ± 6	**65 ± 5** **	**78 ± 2** **	70	**69 ± 4***	**81 ± 3***
Native species monitoring	77	47 ± 4	58 ± 7	**35 ± 5*** **	**59 ± 4*** **	70	**42 ± 5** **	**60 ± 3** **
Additional Management	74	2.4 ± 0.2	3.1 ± 0.3	**1.8 ± 0.3*** **	**2.9 ± 0.2*** **	69	**2.2 ± 0.2** **	**3.0 ± 0.2** **
Restoration frequency	**76**	**0.8 ± 0.1***	**1.7 ± 0.3***	**0.5 ± 0.2** **	**1.3 ± 0.2** **	69	1.0 ± 0.2	1.1 ± 0.2

[1] A natural log transformed variable.

APPENDIX D. Explanation of terminology.

Continued management: is the performance of additional measures to attempt long-term suppression of invasive plant populations. These measures may include population assessment through monitoring, repeating treatment actions and active restoration.

Invasive plant management involves all actions, direct and indirect, necessary to manage invasive plants including planning, mapping, monitoring, sanitary prevention measures, quarantines, and training as well as direct control, habitat manipulation and restoration.

Management area is the area encompassed by the invasive plant management, indirect and treatment actions.

Management methodology (principles) is the set of practices that comprise a general approach to invasive plant management, such as early detection and rapid response or the Bradley method to invasive plant control; 1: Always work from areas with native plants towards weed-infested areas, 2: Make minimal disturbance, 3: Let native plant regeneration dictate rate of weed removal.[1]

Management strategy is a verbal or written plan incorporating one or multiple components of invasive plant management. Strategies may be rudimentary (a verbalized set of ideas) or sophisticated (written and occasionally revised).

Prevent establishment is the exclusion or elimination of self-sustaining invasive plant populations from a site.

Principle focal species is the invasive plant identified as the main target for control.

Successful invasive plant control is the prevention or reduction of invasive plant impacts on a native plant community. Unfortunately, invasive plant impacts are

[1] (Bradley 1988)

largely unknown. Therefore, I use the following three surrogate measures; preventing new invasive species establishment, protecting a native community from invasive species, and reducing invasive plant populations.

Target species are invasive plants that have been the subject of invasive plant management.

Treatment actions are associated with direct suppression of invasive plant populations, including control measures, habitat manipulation (letting the canopy close and changing grazing, nutrient or disturbance regimes, etc.) and restoration.

Treatment area is the area where management practices, treatment actions, have taken place.

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CHAPTER 2

WHY WE STILL DO NOT UNDERSTAND MANAGEMENT EFFECTS

Abstract:

Invasive plant management aims to protect native species and communities through reducing negative ecological impacts of invaders. However, simply reducing invasive plant populations does not automatically translate into healthier native communities; management can even negatively impact native plants. In light of this, different management alternatives, including doing nothing, need to be examined in an ecological as well as economic cost-benefit analysis. This requires understanding long-term management effects, but these are largely unknown because long-term monitoring data is lacking. The importance of both understanding management effects and long-term monitoring has been recognized for many years, but calls to incorporate the required data collection into management programs has had little effect. One possible reason for this is that current incentive structures and organizational competencies do not support long-term management. Changes to the incentive structure and a realignment of competencies may be necessary to encourage management practices necessary for understanding long-term management effects.

In a nutshell:

- Invasive plant management, especially for established populations, does not necessarily benefit native plant communities.
- Despite repeated calls for increased monitoring, effects of long-term management are rarely known.
- Current incentive structure and organizational competencies are may be preventing this desired change.

- Reworking the incentive structure and organizational competencies may facilitate change.

Introduction:

Awareness of the potential negative impacts of invasive species on native ecosystems has increased in recent decades. As a result, invasive species management has become an important component of ecosystem management (D'Amato *et al.* 2008). Invasive species programs require considerable resources (Hulme 2003), but often only limited resources are available and constrain management (Barnett *et al.* 2007; Bergstrom *et al.* 2009). Therefore it is important to understand what types of projects and management actions are most successful. Unfortunately, despite repeated calls for organizations to monitor and record project outcomes, this data is largely unavailable making this type of analysis is difficult (Berry *et al.* 1998). This article examines why this may be occurring through analyzing the funding and organizational environment of forest invasive plant management organizations. I then present possible changes which would encourage goal setting, long-term monitoring and recordkeeping; actions required for understanding the ecological impacts of management.

Managing invasive plants does not necessarily protect native plants:

The overarching goal of invasive species management is to protect native plant communities, or species which depend upon them, but management often focuses on invasive plants. This is warranted when eradicating an invasive species before it has established self-perpetuating populations thus preventing negative impacts from occurring (Simberloff 2003) and in efforts to slow regional spread along invasion fronts (D'Antonio *et al.* 2004). However, when species are prevalent and well established, management needs to be conceptualized as a component of longer-term native community management, not eliminating an invasive species just because it is present (Gobster 2005).

Because early detection is difficult, organizations tend to manage established species and assume that population reduction results in native plant protection. While ecosystems dominated by invasive plants may function differently than uninvaded systems, invasive plants are not necessarily driving ecosystem change (Gurevitch and Padilla 2004; Nuzzo *et al.* 2009). Some invaders may be "hitch hikers", symptoms of ecosystem change rather than causal agents (Didham *et al.* 2005). For example, deer densities in the Northeastern U.S. forests have been increasing (Cote *et al.* 2004; Eschtruth and Battles 2009) and leaf litter has decreased due to invasive earthworms (Nuzzo *et al.* 2009). These changes may be inhibiting the growth of native forbs and creating space for invasive plants to flourish. In this scenario, unless the other pressures are addressed, killing invasive plants will likely create more space for other invaders colonize, not protect native plants.

Invasive plant management can even harm native communities, especially when large populations are managed. For example, a study in Montana grasslands measured the effects of an aerial herbicide application 16 years after treatment and found, contrary to expectations, that two native forbs showed further population declines while the abundance of the invasive plant had actually increased (Rinella *et al.* 2009). A similar effect of accelerated decline of native species as a result of large scale herbicide application was documented for control efforts targeting *Lythrum salicaria* (purple loosestrife) in Minnesota wetlands (Blossey *et al.* 2001). Knowing that invasive management does not always help natives, how can we make the ecological cost-benefit analysis between controlling an invasive plant and doing nothing? Often, the decision is poorly informed because both the invasive species and management impacts are undocumented for non-target species.

Understanding management effects:

To overcome this conundrum, specific management goals must be defined and long-term management effects documented. Management goals for plant communities need to be achievable, not just ecologically, but also given social and economic constraints (Lindenmayer *et al.* 2008). Goals should serve to focus thinking on what the organization ultimately seeks to protect as well as what is being managed, and allow management to be evaluated in relation to a target. Once goals are set, long-term monitoring can be initiated which documents changes in both managed and reference plant populations in relation to specified targets. This monitoring should continue five or even ten years after completion of main invasive treatments because community composition immediately following treatment does not reflect long-term management outcomes (Cox and Allen 2008; Rinella *et al.* 2009). With well planned long-term monitoring, changes in community composition can be attributed to management practices and or to other variables (for example changes in canopy cover). Only then will an understanding of the true effectiveness of a particular management action be recognized.

This is not new advice. Calls for increased monitoring to facilitate science based management (Hobbs and Humphries 1995; Sutherland *et al.* 2004) and reduce resources expended on unsuccessful projects (Smith *et al.* 2006) have been occurring for at least 13 years. However, few organizations have incorporated goal setting and long-term monitoring into their management and a reactive management approach still dominates (Davies and Sheley 2007). In order to institute these new practices organizations need the proper incentives and must have the capability to adapt.

The organizational capabilities are created by organizational competencies which are limited, influence and constrain management, and can determine how successful an organization becomes (Galbreath 2005). According to Wolf and Primmer (2006), competencies can be broadly divided into three categories; external linkages, human capital, and organizational routines. External linkages are the contacts and networks which allow organizations to acquire new knowledge and access the capabilities of other organizations. Human capital is the presence of educated and skilled labor in the organization. Organizational routines are the systems and processes which transform individual knowledge into organizational knowledge. The competencies possessed by invasive plant management organizations were previously unstudied so I included them in my study of forest invasive plant management organizations in the Northeastern United States (Acharya 2009). I will use the data gathered in that study an example of the organizational environment and resources possessed by organizations managing invasive plants.

Current state of affairs:

The 78 organizations I surveyed can be grouped into three categories; land conservation, governmental (national, state or local) and other organizations (environmental education centers, nature centers, Audubon Society chapters and native plant societies). Programs ranged in size and age, but the distribution was skewed towards smaller and younger organizations (Table 2.1). Older organizations tended to have more monetary resources, leaders with more job experience, and were managing more acres of land and more invasive species (Figure 2.1). They also kept records more frequently.

Table 2.1. Descriptive statistics of invasive plant organizations

	Obs	Minimum	Maximum	Mean	Median
General Description					
No. of species	73	1	50	8.6	6
Program age (yrs)	77	2	21	7.1	6
Hectares managed	76	0.1	486	47	10.1
Monetary Resources					
Money spent in a year	75	$0	$150,000	$22,111	$5,000
Monetary resources	69	$28	$59,390	$4,070	$1,700
Human Capital					
Highest degree	76	Bachelors	Advanced	Advanced	Advanced
Conference attendance	76	None	> 1x / year	> 1x / year	> 1x / year
Years of experience	73	2	40	13	10
Labor used in a year					
Staff hours	73	0	3,000	474	120
Volunteer hours	71	0	4,000	380	120
Contractor hours	73	0	1,024	36	0
Total labor	67	6	5,380	940	500
External Linkages					
External information	76	6	56	31	32
Internal Competencies					
Recordkeeping	78	Rarely	Always	Usually	Usually
Assessment	78	Never	Always	Usually	Usually
Reviewing records	76	Never	Always	Sometimes	Sometimes

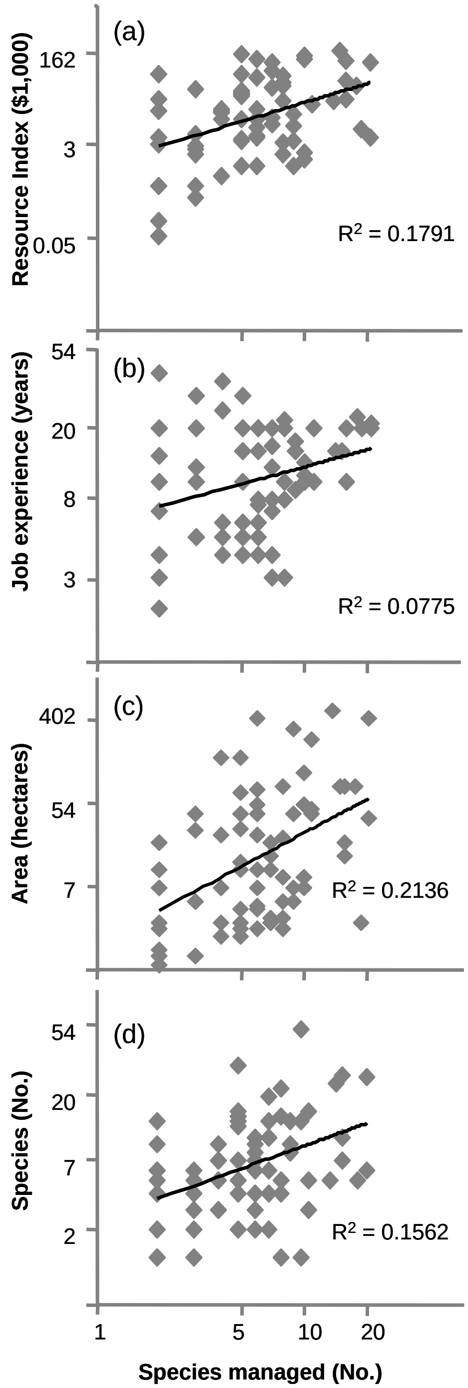

Figure 2.1. Correlation between program age and a) monetary resources including the value of volunteer time, b) years job experience of leaders, c) area of land managed over the last 5 years, d) number of invasive species being managed. Both axis are plotted on a logarithmic scale, but are labeled in untransformed units.

The degree to which organizations found external contacts useful varied greatly, and the total value of external linkages was normally distributed around information sources having "moderate value". Human capital was similar across organizations. Most relied on both volunteers and staff, and had leaders with an advanced degree in the natural sciences who attended invasive species conferences regularly. This means organizations relied on volunteers to perform management, but that management was organized by highly educated leaders. From personal experience, over time, experiential knowledge gained by leaders becomes a source of invaluable and often unrecorded information for organizations.

It is not unusual for this information to be lost if personnel changes. In order for individual information to be captured, organizational information systems and routines must be established. Managers often mention that field work is valued over actions which would create organizational routines such as mapping, planning or monitoring. This is supported by my survey where 50% of leaders spent less than 10% of their time in the office, planning or reviewing their invasive plant management (range: 0 to 80%). In addition, while many organizations kept records (78%), only 30% reviewed their records "at least some of the time". Reviewing records is required for evaluating and understanding of the impacts of management. This suggests that many organizations have weak institutional memory and rely on human capital to evaluate management. However, relying on memory to evaluate long-term effects or impacts of management is problematic due to lapses in memory and the tendency for bias.

These competencies are aligned with an incentive system based on short-term measures of performance; especially grant based funding. When relying on grants, it is common for long-term management to be broken down into discrete projects and funded separately. Monitoring, if supported at all, rarely extends more than one year after invasive species removal even though true results of management are not apparent this soon after project completion (Cox and Allen 2008; Rinella *et al.* 2009). Continued interventions (monitoring, restoration and additional invasive species control) greatly influence management outcomes (Acharya 2009), but are rarely included in grant funding.

Co-evolved with the funding structure is a reward system tied to short-term measures of performance. Managers which treat large areas and kill large quantities of invasive plants are rewarded, not only through project funding, but also with increased internal recognition and media attention. This encourages managers to improve their ability to kill established species, but is unrelated to long-term success protecting natives or reducing invasive plants at a population or landscape level. In addition, using quantity of plants killed as a measure of performance discourages management of populations which are the most likely to be controlled, those that have just been introduced to an area, but are not yet established (Rejmánek *et al.* 2005; Strayer 2009). Finally, these measures of performance relegate important management actions to a secondary importance for example, setting management goals, mapping, or monitoring.

Short-term measures of performance and incentives are one reason long-term monitoring and assessments have not yet been widely adopted. The competencies found within the invasive management organizations are well aligned with this incentive system and therefore it is not surprising that organizations have never developed competencies required for long-term monitoring and assessment.

Organizational change:

Incorporating a long-term and native focused perspective into invasive management requires a shift away from the current incentives and organizational competencies. Educating managers about the importance of goal setting and long-term monitoring will only create a desire for change. Instituting change also requires convincing mid and high-level personnel to change funding, performance measures, and organizational competencies to support this new type of management.

Changes in funding structure would be a good starting point. The current system of splitting up management into smaller projects can backfire, as happened on Macquarie Island where severe ecosystem changes resulted from the control of cats, but not rabbits and rodents because funding for the latter project was still unsecured (Bergstrom *et al.* 2009). Funders need to incorporate management effectiveness, not just project progress, into their standards of performance and recognize management as long-term and ongoing. Doing so would increase the importance of currently undervalued management actions such as, mapping and monitoring, because documentation of management effects would now be required. This may necessitate a shift away from supporting numerous short-term projects to supporting a greater range of management activities on fewer, long-term, projects. Finally, funders could encourage inter-organizational learning by making descriptions of funded projects and any reported outcomes public on databases.

A reworked funding structure would motivate regional managers to change internal performance measures to include management goals and outcomes. For example, if funders were not assessing performance based on how many hectares were treated then there would be less incentive for supervisors to reward for removing five hectares of an invasive species. Instead, both funders and supervisors would reward managers for achieving the agreed upon goal of preventing invasive species from entering an area valued for its native wildflowers. As a result performance standards would realign to recognize the importance of any action integral to accomplishing management goals and documenting management outcomes. This would give managers freedom to perform more effective management, such as early detection and rapid response. It would also increase the value of management actions such as mapping, planning, and monitoring because those actions would now be necessary to document performance.

While the reward system must change to include assessments of management effects, we must also be careful not to punish all negative outcomes. For example, a local manager should not be "punished" if careful monitoring reveals invasive species management has negatively impacted some wildflowers species. Management effects are not always predictable or positive and, unlike our current state of affairs, documentation of management actions and outcomes will mean documented failures in addition to successes. Furthermore, with respect to learning and adapting, documented failures are as important as successes. If managers are punished for negative outcomes, then there will be no incentive to monitor population changes over time and negative outcomes might be under reported. Therefore, learning must also be rewarded such as adapting management based on lessons learned and sharing information through regional forums and databases.

New performance standards would also encourage changes to organizational competencies. In order to document long-term management effects, additional organizational systems and routines would need to be created so that project information, mapping, and monitoring data could easily be referenced years later. In addition, for some organizations the division of labor would need to be revised. Actions like mapping and monitoring require expertise. Organizations currently dependent on unskilled, especially one-time, volunteers would not be able to incorporate these actions without either increasing staff or establishing training programs for their volunteers such as employed by the New England Wildflower Society's Plant Volunteer Conservation Corps Program.

Summary:

The organizational competencies and funding environment in which forest invasive management organizations operate supports short-term, invasive-focused, management. Therefore, it is not surprising that organizational behaviors have been slow to change despite repeated calls to shift to a native-focused approach which documents long-term management effects. Change will only be possible if organizational capabilities and incentive structures also change. Funders need to rethink their granting paradigm to include longer-term management and ecosystem impacts. Internal performance assessments need to incorporate management effectiveness and learning into their standards of performance. These changes would transform many management actions, like monitoring, from secondary importance to required actions. Only then would long-term management effects be understood.

With an organizational realignment that uses management effects as part of their performance standards, managers could stop focusing only on killing invasive plants and start focusing on managing ecosystems. They would also be able to conduct an ecologically based cost-benefit analysis as to the best management strategies to adopt. Over time, resources could be concentrated on projects which are having the most ecological impact. Finally, data generated could be shared and studied so that generalized invasive management principles could be established.

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