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The Ecology of Land Managers in Riparian Restoration

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THE ECOLOGY OF LAND MANAGERS IN RIPARIAN RESTORATION

A Thesis
Presented to
the Faculty of Natural Sciences and Mathematics
University of Denver

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Lisa B. Clark

June 2018
Advisor: Anna A. Sher
ABSTRACT

While previous studies in restoration ecology have focused on the efficacy of direct management actions, the driving forces on management decisions (e.g., managers’ characteristics or attitudes, environmental conditions) and the indirect impacts on restoration outcomes from management decisions (such as whether to collaborate) are quantified here for the first time. As a case study, I used data from 244 sites across the riparian Southwest US where the invasive shrubby tree *Tamarix sp.* was removed using various different methods. I surveyed and interviewed the 45 land managers who were responsible for the removal projects to determine their characteristics, attitudes, and management decisions. I found differences between agencies in which removal methods were used and project objectives (i.e., goals); goals were also correlated with climate (i.e., temperature and precipitation). Surprisingly, neither education nor any other characteristic measured predicted attitudes held by managers about science and/or nature. The resulting plant community after restoration (as measured by four PCA vectors) was associated with the governing agency or organization and the manner in which each manager prioritized management goals. Finally, managers’ attitude toward nature was related to plant community composition after restoration, while not associated with any measured manager characteristics or decisions, suggesting that there were subtle interactions at play. This study contributes to our understanding of what makes
restoration projects successful and how to improve restoration outcomes by understanding the managers themselves.
ACKNOWLEDGEMENTS

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CHAPTER ONE: RESTORATION ACTIONS AND MANAGEMENT
DECISIONS ASSOCIATED WITH MANAGER TRAITS AND
ENVIRONMENTAL CONDITIONS IN TAMARIX REMOVAL PROJECTS

Introduction

Studies in restoration ecology have explored how management decisions and environmental conditions can affect the ecosystems that result following restoration, but rarely have restoration studies tested what factors drive management. It is well-documented that backgrounds and belief systems influence decision making (e.g., Martin-Lopez et al. 2007, Roche et al. 2015, Hagger et al. 2017), so it follows that the same principle may apply to land managers. It is important for researchers to understand what restoration decisions managers are making, and why they are making those decisions in order to most effectively improve and inform costly restoration efforts. Most land management studies investigate the relationships between demographics of the general public and attitudes toward conservation to gain insight on how to foster public awareness and approval of restoration efforts (e.g., Bremner and Park 2007, de Groot and de Groot 2009, Admiraal et al. 2017). For example, in Australia, the mission statements of stakeholders – which included but was not limited to land managers – predicted how project goals were prioritized; community and local organizations were more focused on social goals while state and private organizations were concerned about biodiversity (Hagger et al. 2017). Additionally, while many studies have generally inventoried
management actions in restoration projects (González et al. 2015), never has the relationship among the characteristics of managers, management decisions, attitudes of managers, and local conditions been quantified to gain a better understanding of the complexities of restoration efforts (hypothesized relationships in Figure 1.1).

![Diagram](image)

Figure 1.1: Graphic representation of research hypotheses: a) manager characteristics (black box) predict management decisions (middle boxes) and attitudes (red box), and attitudes predict management decisions; b) environment (blue box) predicts manager characteristics and management decisions. Different shades of the box colors for management decisions, attitudes, and environment variables are consistent with all other figures in Chapter 1.

While there are no quantitative studies, there is qualitative evidence for the driving forces of some restoration decisions made by land managers, though most studies only focus on one aspect of decision-making. For example, some research projects have provided qualitative snapshots of how specific regional partnerships can facilitate successful restoration, such as by disseminating scientific information (Kallis et al. 2009) or planning flexible but detailed goals and by monitoring (Oppenheimer et al. 2015). Rissman and Sayre (2012) conducted a qualitative exploration of rangelands that highlighted the idea that social interactions and politics drive decisions related to easement conditions, but did not consider other aspects of decision-making. In another study, researchers found that systematic and objectively clear monitoring by managers
was associated with a more realistic perspective on the success of restoration (Morandi et al. 2014). Project goals were inventoried in US river restoration projects through the National River Restoration Science Synthesis (NRRSS), which revealed that water quality management or in-stream habitat improvement were the most common primary goals (Bernhardt et al. 2007, Kondolf et al. 2007), but it has not been tested whether those goals were selected due to ecological conditions or some other factor such as politics, as suggested by Rissman and Sayre (2012). There have not been any comprehensive inventories of both the characteristics and decisions of land managers in any one system or investigations of what characteristics may influence management decisions.

**Recommendations and hypotheses from restoration studies**

Restoration scientists have made many recommendations to managers for how to improve the outcomes of their restoration projects; the five most common of these recommendations are related to project goals, collaboration, information sources, project monitoring, and direct restoration actions. It has been recommended that managers establish reasonable goals that can be accomplished and assessed, both based on novel ecological conditions (e.g., previously mesic areas that shifted to xeric) and logistics (e.g., funding, staff, time; Shafroth et al. 2008, González et al. 2017a). Next, collaboration with other agencies and with researchers is frequently recommended to managers as it may widen the scope of restoration projects as well as create the opportunity for managers to learn from others’ mistakes as well as their own (Bernhardt et al. 2007). Where managers get their information from may also be important, an aspect that is closely related to collaboration; it has been recommended that managers
supplement advice from peers and past experience with evidence-based sources (Sutherland et al. 2004). Additionally, researchers have suggested that monitoring is crucial to the success of restoration projects (Palmer et al. 2005, England et al. 2008, Shafroth et al. 2008). However, monitoring could be easily influenced by legislative requirements (Kondolf et al. 2007, González et al. 2017a) or even public perception and involvement (Bernhardt et al. 2007). Finally, the direct actions (active restoration measures, e.g., how invasive species are removed) used to restore ecosystems have been shown to be crucial to the success of restoration projects (e.g., Carter and Blair 2012, González et al. 2017c); I expect that the decision to use one particular direct action over another can be affected by managers’ characteristics or climatic conditions.

Despite the evidence that governing organization (i.e., “agency”) may drive decisions, there is no research on whether that effect is stronger than the potential effect of characteristics of individual managers within those agencies; as a starting point, I focus here on education level, management experience, and management role. The education level of the manager is expected to strongly influence practices related to science, as seen in Europe where scientific information was more difficult to understand for individuals in the general public who had lower education levels (Pardo and Calvo 2006). I also expect that the amount of time managers have been in the profession (i.e., experience) will affect management decisions as they utilize lessons learned from past mistakes and would have a better understanding of how the system will respond to particular approaches. However, specific experience in each project location may not predict management decisions toward objectives. As a manager becomes more familiar with an area, they are likely to have a better sense of what is feasible as well as what is needed, but that end goal would
not be the same from place to place (Holling and Meffet 1996). The final characteristic of managers that I consider here is the individual role of managers in restoration projects. Similarly to experience level, I expect that a manager who has more roles in management (e.g., oversee a project with input from a partnership, implement decisions others made, collect data) – and is thus more involved in the project – will make different management decisions than a manager who is less involved. Also, these characteristics might not be equally distributed across agencies due to self-selection through job qualifications (i.e., required education level or amount of experience), so I expect to see that the effect of agency on management decisions will be related to individual managers’ characteristics.

Attitudes

In addition to individual managers’ characteristics, the attitudes of managers also have the potential to impact what management decisions are made, and two of these have been suggested by the literature to be particularly important but have never been empirically tested: attitude toward science and attitude toward nature (i.e., relationship with nature). Attitudes of managers towards science are widely assumed to be an important driver of management action in the literature (e.g., Bernhardt et al. 2007, Stromberg et al. 2009). Knowledge and communication gaps between researchers and managers have been identified as contributing to the variability in restoration success (Palmer 2009, Stromberg et al. 2009), and it is assumed that good communication and collaboration between managers and researchers is needed in order to have successful projects (Bernhardt et al. 2007). Scientific practices can be used in all phases of restoration projects from gathering information (e.g., primary literature; Sutherland et al.
2004) to planning (e.g., replicated design with controls; González et al. 2017a) to evaluation (e.g., clear and quantifiable goal assessment; Kondolf et al. 2007, Nilsson et al. 2016), but whether characteristics of managers can predict the use and perception of science – or the translation from a positive attitude toward science to using scientific practices – has never been empirically tested.

The other aspect of attitudes I will investigate is how managers view their relationship with nature. How managers perceive their relationship with nature may influence how they approach projects and what practices they are willing to use, but there are no studies that have quantified this relationship. For example, Curtis and de Lacy (1998) found that most private managers (who were also the landowners) in rural Australia followed a strong stewardship ethic, but the study did not evaluate whether that ethic directly affected management actions. Relationship with and perceptions of nature in the general public have been studied widely (e.g., van den Born et al. 2001, Butler and Acott 2007, Gobster et al. 2007); in this study I apply a similar framework to land managers.

**Climate**

Just as the abundance of invasive plants (common targets for restoration efforts) is influenced by environment (McShane et al. 2015), geographic location and environmental conditions (i.e., climate) may also drive where particular managers choose to work and the management decisions they make. While it seems intuitive that managers would focus on the major issues in each area (e.g., focus on invasive removal in locations with high levels of invasion), the political constraints for a given river basin may also
influence what management actions are possible both based on available funding and relevant legislation. For instance, some state governments require collaboration through watershed partnerships (such as New Mexico) while others do not. In some cases, interpretation of national policies can differ between regions even within the same agency; for example, compensatory actions as a part of the US Clean Water Act differed by state and by district (for US Army Corps of Engineers) based on what environmental issues were locally important (Doyle et al. 2013). I expect that the dominant characteristics of individual managers will also vary by geographic location; for example, managers with a higher education level may want more of a challenge so may work on projects in more arid regions where it can be more difficult to do restoration. Finally, due to the availability of resources, I expect management decisions to vary based on environmental conditions as well. For example, some projects may be more physically isolated from others due to a lower population density in harsher conditions, making collaborations more difficult and costly. If particular resources such as water are less available, managers may be more likely to prioritize actions that conserve water than if they are working in a region that is wetter; if plants are especially hard to grow because of harsh temperatures, managers may invest more resources into facilitating that growth.

Study questions

A study of this nature and scope has not been conducted before now. Little is known about what drives restoration decisions made by land managers, and this study takes the first step in addressing this gap in knowledge. There have been quantitative studies which inventory decisions being made (e.g., González et al. 2015) and qualitative
reviews of either individual projects (e.g., Oppenheimer et al. 2015) or driving forces of
decision-making in other populations (e.g., Rissman and Sayre 2012), but this is the first
time mixed methods have been used to understand land managers’ decision making in the
context of restoration.

I used a dataset of 244 sites from riparian restoration projects across the
southwestern US as a case study to address the following three questions using methods
of analysis typical for ecological research: 1) can characteristics of managers predict
management decisions, 2) can attitudes of managers predict management decisions or be
predicted by managers’ characteristics, 3) do manager characteristics follow any
geographic patterns, and 4) can environmental conditions predict management decisions
(as summarized in Figure 1.1)? I expected to find that manager characteristics (i.e.,
agency, education, experience) predict management decisions and managers’ attitudes
toward science and nature, but that managers’ attitudes would not strongly predict
management decisions as the needs or goals of the agencies they work for may
overshadow the individual managers. In contrast, I predicted that those managers who
had a more positive attitude toward science specifically would follow more scientific
recommendations, work with more scientists, and use scientific literature to inform
management decisions.

Methods

Case study: The Southwest US

Across the Southwest US, the health of riparian systems has declined over the
past few decades because of issues such as overgrazing, modified flows due to diversions
and dams, and non-native plant invasions (Briggs et al. 1994, Shafroth et al. 2002, Stromberg et al. 2007). One of the most pervasive invasive plants is *Tamarix spp.* (tamarisk, saltcedar), a shrubby tree that can grow in monocultures along riverways and impacts wildlife habitat (reviewed in: Bateman et al. 2013, Sogge et al. 2013, Strudley and Dalin 2013), soil salinity (reviewed in Ohrtman and Lair 2013), and native plant communities (Friedman et al. 2005, Merritt and Poff 2010). *Tamarix* removal is a common practice in river restoration projects, and there are many methods managers use to remove the invader. Methods include mechanical removal using heavy machinery (“heavy machinery”), smaller-scale mechanical removal using a chainsaw or handsaw then spraying herbicide on the stump (“cut-stump”), and prescribed or accidental fire (“burning”). As these methods can be very costly and potentially damaging to native vegetation, a biocontrol agent, *Diorhabda spp.*, is also used to target *Tamarix* (“biocontrol”). *Diorhabda* was first released in 2001 (Dudley and DeLoach 2004) and has spread across most of the Southwest US (Tamarisk Coalition 2017). These projects are conducted on lands owned by a variety of agencies including federal (e.g., Bureau of Reclamation), state (e.g., state natural resource departments), local (e.g., conservancy districts), and non-profit/private (e.g., The Nature Conservancy). The same projects are conducted by managing agencies that are not always the same as the owning agency. The diversity of overall management approach and the widespread nature of *Tamarix* removal projects make riparian restoration in the Southwest US the ideal system to study the relationships among manager characteristics, attitudes, management decisions, and local conditions.
I identified land managers of *Tamarix* removal projects included in a large dataset compiled by González and others (2017b, c) that was originally collected to assess the effects of removal method on vegetation, representing 244 treated sites. These sites were distributed across the Upper Colorado, Lower Colorado, and Rio Grande river basins in the southwestern US and encompassed lands owned by a variety of public and private management agencies (Figure 1.2). From this dataset, I used climatic, location, and removal method data (see González et al. 2017b).

**Study terms**

*Managers* were defined as individuals who made management decisions on one or more projects, including job titles such as restoration ecologist, wildlife biologist, hydrologist, program manager, planner, or superintendent. A *project* consisted of one or more *sites* (the final observation at one specific location) where the managing and owning agency, as well as the project goals, were the same. I determined there to be 80 projects among the 244 sites. Some managers had more than one project, and some projects were collaboratively managed by multiple individuals. Variables that were specific to individual projects were considered *project level* variables, while variables that applied to each manager regardless of the project were considered *manager level* variables (Figure 1.3).
Figure 1.2: Distribution of the 244 treated *Tamarix* removal sites in the southwest U.S. encompassing the Colorado (Upper and Lower) and Rio Grande catchments. 79 undesirable reference sites representing the condition before *Tamarix* removal and 93 desirable reference sites representing the ideal outcome are also included. The pie charts indicate the proportion of sites owned (left) or managed (right) by each type of agency within each river basin.
Figure 1.3: Star schema of dataset used in this study. Orange boxes represent site-level data previously collected (Gonzalez et al. 2017), blue boxes are project-level data, and green boxes are manager-level data.
There were three general categories of variables for the manager data. The first was *manager characteristics*, which refers to underlying traits of managers. The second category was *management decisions*, which were the restoration decisions managers made both in specific projects and for more general approaches such as collaboration. The final category was *manager attitudes*, covering a qualitative assessment of attitudes toward both science and nature.

**Survey data**

To collect data on manager characteristics and management decisions, I created and distributed an online survey administered through Qualtrics to land managers. I tested the 20-minute survey through multiple iterations using mock interviews and through Qualtrics by trusted land managers and collaborators to ensure clarity (see Appendix A for full survey), and the survey was approved by the University of Denver Institutional Review Board (#816375-5). The survey period was open from August 2016 to March 2017. I contacted 46 managers via email or phone with the help of E. González and collaborators; only one manager who was contacted did not complete the survey.

The resulting survey results encompassed 78 projects (227 treated sites; 93% of those originally sampled for vegetation data). I also interviewed 22 of the 45 managers who completed the survey. Seventeen managers had more than one project and 54 projects had multiple managers. Some of the variables are related to each manager, while others are related to specific projects. Thus, I could consider survey data in terms of managers (n=45), projects (n=78), and sites (n=227; Figure 1.3); I did not test questions about the relationships between manager-level characteristics (e.g., education) or
attitudes and project-level decisions (e.g., goals) or between project-level characteristics (e.g., managing agency) and manager-level decisions (e.g., collaboration) or attitudes because those analyses would have required more complex mixed models which was outside the scope of this thesis.

The survey covered two main topics: manager characteristics and management decisions. I randomly assigned each manager a code and then gave the managers additional codes for each of their projects via email before they took the survey. This allowed me to retain confidentiality but maintain the ability to link responses to the correct treatment sites. The seven specific manager characteristic variables included: agency (1-3), education (4), experience level (5-6), and management role (7; Table 1.1): 

Agency. I considered the governing agency or organization, referred to here as simply “agency,” on both the manager (employing agency) and project (managing and owning agency) levels, as it was not the same in many cases. Each variable consisted of five categories. Managing and owning agency had similar categories: private/non-profit (also university for owning agency), local, state, federal, and collaborative (i.e., more than one agency). Employing agency had separate categories for private and non-profit/university and did not have a “collaborative” category. In some cases, there were slight discrepancies between co-managers on the ownership or managing agency of a project. In those cases, I used the response data from the primary manager, as defined as the person who had the greatest number of the following characteristics: present at the time of data collection, had a direct decision-making role and/or widest breadth of roles, and/or was identified as such in the interviews.
Table 1.1: All survey variables used for analysis. The associated survey question number (Appendix A) indicated in parentheses. More information is located in the methods of Chapter 1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Variable type</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager characteristics</td>
<td>categorical</td>
<td>1. Employing agency (pers. comm.)</td>
<td>Private, non-profit, local, state, federal</td>
</tr>
<tr>
<td></td>
<td>categorical</td>
<td>2. Managing agency of project (7-8, 15)*</td>
<td>Private/non-profit, local, state, federal, collaborative</td>
</tr>
<tr>
<td></td>
<td>ordinal</td>
<td>3. Owning agency of project (4-6, 12-14)*</td>
<td>Private/non-profit, local, state, federal, collaborative</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>4. Education (39)</td>
<td>High school, Bachelors, Masters, PhD</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>5. Overall experience (2)</td>
<td>&lt;11 years, 11-20 years, &gt;20 years</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>6. Experience in project area (16)*</td>
<td>&lt;11 years, 11-20 years, &gt;20 years</td>
</tr>
<tr>
<td></td>
<td>categorical</td>
<td>7. Management role (1)</td>
<td>Number of roles out of a possible 5 (see Appendix B)</td>
</tr>
<tr>
<td>Manager decisions</td>
<td>continuous</td>
<td>1-5. Priority of goals (17-18)*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>categorical</td>
<td>6. Highest priority goal (18)*</td>
<td>Plant, people, water, wildlife, other</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>7. Number of collaborating groups (36)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>8. Number of monitoring groups (26)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>9. Number of collaborating scientist groups (37)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>categorical</td>
<td>10. Number of researching groups (38)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>11. Type of information sources (21-23, interviews)</td>
<td>Formal, informal, mixed</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>12. Number of information sources (20)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>13. Number of monitoring methods (27)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>ordinal</td>
<td>14. Frequency of monitoring (28, 30, 32, 34)</td>
<td>Variable or &lt;every 4 yrs, every 1-2 yrs, &gt;annual</td>
</tr>
<tr>
<td></td>
<td>continuous</td>
<td>15-18. Removal method (González et al. 2017b)*</td>
<td>Proportion of sites with each method for manager or within a project</td>
</tr>
<tr>
<td>Manager attitudes</td>
<td>continuous</td>
<td>Attitude toward science (interviews)</td>
<td>Scale – negative (“Polarized”) to positive (“Integrated”)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relationship with nature (interviews)</td>
<td>Degree of adherence for “Developer”, “Guardian”, “Spectator”</td>
</tr>
</tbody>
</table>

*Variable specific to projects
*Variable not included in cluster analysis
**Education.** Managers selected their highest achieved education level out of four possible options: high school, Bachelor’s degree, Masters degree, or Doctorate.

**Experience.** Experience level was considered using ordinal categories (i.e., less than 11 years, 11-20 years, or more than 20 years) both on the manager level as an overall measure of management experience and on the project level as a measure of location-specific experience.

**Role.** Management role was the only continuous manager characteristic variable. I recorded it as the number of roles respondents took on for all projects (a discrete numerical value; see Appendix B for role options).

The 18 specific *management decision* variables covered the manager’s prioritization of goals for each project (1-6), degree of collaboration (7-10), selection of information sources (11-12), monitoring methods (13-14), as well as removal method (15-18; Table 1.1):

<table>
<thead>
<tr>
<th>Goal group</th>
<th>Specific goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td>Improve native plant diversity, exotic plant removal, ecosystem resilience</td>
</tr>
<tr>
<td>People</td>
<td>Recreation, aesthetics, wildfire mitigation</td>
</tr>
<tr>
<td>Water</td>
<td>Channel maintenance, restore over-bank flooding, water quality</td>
</tr>
<tr>
<td>Wildlife</td>
<td>Endangered species, habitat improvement</td>
</tr>
<tr>
<td>Other</td>
<td>Livestock, water conservation, salinity, research, none, unknown</td>
</tr>
</tbody>
</table>

**Goal prioritization.** For the project-specific management decision variables, managers selected and then ranked goals for each project. There were 14 goals to choose from, including an “other” option where managers could write in additional goals. After selecting their goals, managers ranked them in importance for that project. I assigned
these ranks a low, mid, or high priority (1, 2, or 3) based on tertile for each project. To reduce the number of variables, I combined the goals into five groups based on similarity (plants, people, water, wildlife, and other), by calculating the mean priority value (Table 1.2). The highest priority type of goal was also recorded as a categorical variable.

Collaboration. Multiple-choice responses for general collaboration, collaboration for monitoring, science-specific collaboration, and collaboration for research were recorded as a count of the number of groups managers work with (e.g., personnel within their agency, university scientists, local managers, etc.; see Appendix B for specific options for each variable).

Information. Managers were asked to rate the influence of information provided by particular agencies or organizations on their decision-making. After doing the interviews, I discovered that this question was interpreted in many different ways by respondents – some managers focused on people they work with, some focused on sources of funding, and others responded to the question as intended with published information in mind. To mitigate the effect of this variation, this question's answer was simply recorded as a count of the number of influential sources rated “somewhat influential” or higher. I also developed a categorical variable for the type of information source: informal (e.g., face-to-face interactions, networking), formal (e.g., published sources, conference presentations), or a mix. This variable was based on the qualitative assessment made by research assistants of open-ended questions and interview responses where available (following methods in Saldaña 2014), double-checked by me for accuracy and consistency.
**Monitoring.** I recorded the types of monitoring methods used by managers (i.e., visual, biological, physical, or chemical; see Appendix B) as a count to represent the number of methods. In the survey, managers also selected monitoring frequency for each type of monitoring used but because of small sample sizes for the physical (e.g., channel cross-sections or pebble counts) and chemical (e.g., water temperature or dissolved oxygen) methods, I created an ordinal variable for overall monitoring frequency where the highest frequency for any method was recorded.

**Removal.** Removal method was previously recorded in the dataset on a site-by-site basis, so I calculated a proportion of each type of *Tamarix* removal (biocontrol only, heavy machinery, burning, and cut-stump) both for the total number of sites in each project and the total number of sites for each manager. In the rare cases where more than one method was used, a site's removal method was considered the most physically disturbing method used (González et al. 2017b; burning > heavy machinery > cut > biocontrol).

**Analysis of characteristics predicting management decisions**

Due to the large number of variables I collected data for, I used cluster analyses to determine how variables within each category were associated with each other. I ran five different cluster analyses (manager characteristics, project-specific characteristics, general management decisions, project-specific decisions, and for the relationship with location, all manager variables) with help from Dr. E. González at Colorado State University using partitioning around medoids (PAM method, Kaufman and Rosseeuw 1990) where the number of clusters is estimated by the optimum average silhouette width using the function pamk of the package fpc (Henning 2015) in R 3.4.1 (R Core Team...
The silhouette width indicates the distance of an individual within groups as compared to the distance between groups. The dissimilarity matrix that was used to feed the PAM procedure was created using Gower distances (Gower 1971, Legendre and Legendre 2012), computed with the function daisy of the package cluster (Maechler et al 2017) in R 3.4.1 (R Core Team 2017). Gower distances were used because they allow combining categorical, ordinal and continuous variables, and can still be computed if missing values are present. The PAM method is an alternative for k-means clustering when means for the different clusters cannot be computed. I based the number of cluster groups on a realistic interpretation while maximizing the average silhouette width (ASW), then determined significant differences between groups using chi-square or Mann-Whitney U comparisons for each variable (Table 1.3).

I then used the cluster analysis results to determine which variables would be tested individually; those variables that significantly drove the cluster group structure could be represented by the variable with the lowest p-value, whereas those that did not were all included in the analyses. The project-specific characteristic cluster analysis yielded two groups that were defined by local experience, managing agency, and owning agency (Table 1.3-1). The manager characteristic cluster analysis yielded two groups characterized by employing agency, experience, and education (Table 1.3-2). Thus, I concluded that I only needed to test the relationships with the following characteristic variables: management role, employing agency, and managing agency. A cluster for project-specific management decisions was also created, but did not yield a realistic interpretation – one group had projects where “other” goals were most commonly used, and the other group had a high priority of all other goals – so this cluster did not allow for
Table 1.3: Differences between cluster groups created from 1) manager characteristics, 2) project-specific characteristics, and 3) general management decisions. Clusters created using partitioning around medioids (PAM method) with Gower distances; average silhouette width (ASW) given as an indication of the strength of the cluster structure. Shown are the percentages of all managers in each group who selected each management role, the median value of each group for continuous variables with the range in parentheses, or the most commonly selected category. Sample sizes for 1 and 3 are the number of managers in each group, and sample sizes for 2 are the number of projects in each group. Coefficients are either Pearson’s chi-square (categorical variables) or Mann-Whitney U (continuous variables). Significant results are bolded (p<0.05).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group 1</th>
<th>Group 2</th>
<th>coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1) Manager characteristics (ASW=0.22)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct management role$^+$</td>
<td>71%</td>
<td>65%</td>
<td>0.17</td>
<td>0.68</td>
</tr>
<tr>
<td>Implement decisions made by others$^+$</td>
<td>29%</td>
<td>22%</td>
<td>0.34</td>
<td>0.56</td>
</tr>
<tr>
<td>Oversee projects with input from a partnership$^+$</td>
<td>75%</td>
<td>57%</td>
<td>1.79</td>
<td>0.28</td>
</tr>
<tr>
<td>Collect data$^+$</td>
<td>46%</td>
<td>30%</td>
<td>1.18</td>
<td>0.28</td>
</tr>
<tr>
<td>Median breadth of management roles (0-4)$^+$</td>
<td>3</td>
<td>3</td>
<td>2.18</td>
<td>0.14</td>
</tr>
<tr>
<td>Most common experience level</td>
<td>&gt;20 years</td>
<td>11-20 years</td>
<td>11.55</td>
<td>0.009</td>
</tr>
<tr>
<td>Most common education level</td>
<td>Bachelors</td>
<td>Masters</td>
<td>8.46</td>
<td>0.04</td>
</tr>
<tr>
<td>Most common employing agency</td>
<td>Federal</td>
<td>Non-profit/University</td>
<td>39.97</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>2) Project-specific characteristics (ASW=0.51)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most common local experience level</td>
<td>11-20 years</td>
<td>&lt;11 years</td>
<td>8.84</td>
<td>0.01</td>
</tr>
<tr>
<td>Most common managing agency</td>
<td>Collaborative</td>
<td>Private/Non-profit</td>
<td>63.28</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Most common owning agency</td>
<td>Federal</td>
<td>Private/Non-profit/University</td>
<td>53.87</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>3) Management decisions (ASW=0.17)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most common type of information sources</td>
<td>mix</td>
<td>mix</td>
<td>6.12</td>
<td>0.05</td>
</tr>
<tr>
<td>Median breadth of information sources (0-22)</td>
<td>18</td>
<td>19</td>
<td>0.09</td>
<td>0.76</td>
</tr>
<tr>
<td>Median breadth of monitoring groups (0-6)</td>
<td>2</td>
<td>4</td>
<td>10.40</td>
<td>0.001</td>
</tr>
<tr>
<td>Median breadth of monitoring methods (0-4)</td>
<td>2</td>
<td>4</td>
<td>13.33</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Most common monitoring frequency</td>
<td>every 1-2 years</td>
<td>&gt; once a year</td>
<td>5.00</td>
<td>0.17</td>
</tr>
<tr>
<td>Median breadth of collaborating groups (0-7)</td>
<td>2</td>
<td>4</td>
<td>12.23</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Median breadth of science collaborators (1-7)</td>
<td>3</td>
<td>5</td>
<td>3.43</td>
<td>0.06</td>
</tr>
<tr>
<td>Median breadth of researching groups (0-4)</td>
<td>2</td>
<td>2</td>
<td>2.39</td>
<td>0.12</td>
</tr>
</tbody>
</table>

$^+$5% weight; other manager characteristics have 25% weight
the reduction of any variables. There were two groups from the general management decision cluster analysis as well, significantly distinguished by type of information source, monitoring collaborations, monitoring methods, and general collaboration (Table 1.3-3). Therefore, the general decision variables were reduced to the following: number of information sources, monitoring frequency, general collaboration, science collaboration, and research collaboration.

To determine the relationships between manager characteristics and management decisions, I tested variable-pair relationships with these reduced sets of variables using non-parametric Spearman’s rho regressions, Mann-Whitney or Kruskal-Wallis tests, Pearson’s chi-square, and logistic fit tests, depending on the format of each variable. To account for the increased risk of a Type I error due to the large number of tests, I applied a Bonferroni adjustment to the alpha based on the number of analyses for each sub-question. For example, when analyzing the relationship between agency and management decisions, an alpha of 0.05 was divided by 19, which is the total number of decision variables for the sub-question “how does agency influence management decisions”. I also used an adjusted alpha in pairwise comparisons of categorical independent variables as a post hoc test for the Kruskal-Wallis analyses.

Manager attitude data collection and analysis

I used interviews to obtain data on the attitudes of land managers. I conducted these almost entirely with managers who completed the survey, though one manager was interviewed who did not take the survey. The interviews were in a semi-structured format and were given in person at a location of the manager’s choice; I conducted one interview
over the phone due to scheduling difficulties. I designed the questions as a follow-up to the survey and thus expanded on subjects of past experiences, success, partnerships and collaboration, working with scientists, and information sources (Appendix A). All interviews were recorded and then transcribed by research assistants and checked by me so that they could be coded for themes. The coding was an iterative process. I tagged phrases or statements from the transcriptions with the idea or attitude being expressed (“code”) and then organized the codes based on similarity in themes (Auerbach and Silverstein 2003, Saldaña 2009). Specifically, I was looking for attitudes toward science and relationship with nature.

For attitudes toward science, I asked some leading questions (Appendix A) but most of the responses that were coded were unsolicited. There were two distinct attitudes that emerged from the data (Appendix C, Figure S1.1): the idea that practitioners and academics are very separate and do not exchange a lot of information (which I refer to as “Polarized” here) versus the idea that practitioners use a lot of science and scientific skills and/or work closely with scientists (“Integrated”, Table S1.1 for associated codes). For both groups, I weighted specific codes. If a manager was particularly adamant or used strong language, I multiplied the code by 2 to represent a stronger alignment with the related attitude; if a manager was talking more about the views of their agency or seemed displeased about what they were talking about, I divided the code by 2 (see Table S1.2). Then I assigned negative values to the Polarized codes and positive values to the Integrated codes and added those values together for each manager. A positive value indicated a more Integrated attitude toward science and a negative value indicated a more Polarized attitude toward science.
I based the framework for relationship with nature loosely on the humans-and-nature scale ("HAN scale", de Groot et al. 2011). The HAN scale has only been studied with laypeople’s reactions to statements about nature, so the scale will necessarily be different for managers who are a smaller subset and a very specific population that has been shown in other regions to be more inclined toward a stewardship mindset (Curtis and de Lacy 1998). I classified statements made by managers in interviews as being in one of three different attitude categories: humans are above nature and use technology to develop nature for the benefit of humans (“Developer”), humans and nature are equal and humans have to take care of nature so that nature is still healthy for future generations (“Guardian”), and humans are a small part of nature as a whole and nature will take its course regardless of human actions (“Spectator”; Appendix C: Figure S1.1, Table S1.1). Thus, I was able to determine the degree to which managers aligned with each of these attitude categories. The managers did not generally fall into only one of these attitude categories because most managers made statements associated with more than one category. I weighted the codes in a similar fashion to the science attitude codes, but I calculated them as a proportion of the total number of codes for each manager. In this way, the value for each attitude represented how important that attitude was for each manager overall.

To answer the question of how manager characteristics relate to attitudes and how attitudes relate to management decisions, I used non-parametric Spearman’s rho regressions, Mann-Whitney or Kruskal-Wallis tests (for categorical characteristics), and logistic fit tests (for categorical decision variables), with a Bonferroni adjustment.
Environmental data

To quantify whether geographic location or the environment were associated with manager characteristics and management decisions/attitudes, I used previously collected variables on location (river basin) and climate (precipitation and temperature; González et al. 2017b) as independent variables and the reduced variables for project and manager characteristics, decisions, and all attitudes as dependent variables. The three river basins were the Upper Colorado, Lower Colorado, or Rio Grande basins. I used Kruskal-Wallis and Pearson’s chi-square tests with a Bonferroni adjusted alpha to analyze differences between river basins in manager characteristics, management decisions, and manager attitudes.

Climate has been shown to partially explain the plant community responses to Tamarix control at a local level (Bay and Sher 2008, González et al. 2017b) and overall Tamarix distribution at a continental level (McShane et al. 2015), so I hypothesized that climate would also help predict manager characteristics (by influencing where managers choose to work) and management decisions at a river basin level. I used normal (average over 30 years) annual precipitation (mm), normal annual minimum temperature (°C), and normal annual maximum temperature (°C) averaged for the sites within each project or for each manager, depending on the level (i.e., project or manager) of the response variable. I also analyzed the relationship between local conditions and managers as a whole, using the cluster groups created from all of the manager-level variables (Appendix E, Table S1.3). I used non-parametric Spearman’s rho regressions (adjusted alpha) for the climatic variables with the continuous characteristic, decision, and attitude variables; I
used logistic fit tests (adjusted alpha) for climate with categorical characteristics and decision variables.

**Results**

A variety of managers participated in the survey. Of the 45 participants, 21 were men and 24 were women. Most managers had a masters degree (47%), followed by managers with a bachelors degree (33%); 8 managers had a doctorate, and only 2 had no more than a high school diploma. A variety of specific agencies was represented. There were 14 owning agencies including: 4 federal agencies (primarily National Park Service with 16.7% and Bureau of Land Management with 15.4% of projects), 6 state agencies (primarily state park service with 9% of projects), 4 local agencies (including municipalities, regional districts, and tribal lands, 11.6%), 5 private organizations/individuals (14.2%), and 11.5% of projects were owned by more than one agency. There were 11 managing agencies including: 4 federal agencies (15.4% of projects, primarily Bureau of Land Management), 2 state agencies (one project each), 3 local agencies (6.5%), 5 private organizations/individuals (9%). However, most were collaboratively managed with more than one agency (55.1%). There were also 21 different employing agencies including: 5 federal agencies (primarily Bureau of Land Management with 8 managers), 4 state agencies (5 managers), 7 local agencies (7 managers), 5 non-profit organizations (including two land trusts, 7 managers), one private consulting firm (2 managers), and two self-employed individuals.
Manager characteristics explain management decisions

There were no significant relationships between manager characteristics and management decisions (Table 1.4). However, there was a trend between both the prioritization of goals and the *Tamarix* removal method with managing agency. Municipally managed projects had people-related goals as a slightly higher priority than federally managed projects did (Appendix E, Figure S1.2). Federally managed and owned projects had slightly more biocontrol-only sites than local or state projects that had none (Figure 1.4). Collaboratively managed projects tended to have more sites with cut-stump removal than federal, state, or private. Federally managed projects tended to use heavy machinery significantly more often than collaboratively managed projects. Employing agency was slightly associated with general collaboration, with private managers collaborating less than all other managers. However, there were only two private managers, so when they were excluded, there was no difference between employing agencies for rate of collaboration (*H*=5.58, *df*=3, *p*=0.13). Thus, employing agency did not predict management decisions.
Table 1.4: Relationship between manager characteristics (columns) and management decisions (rows). General management approach response variables (a) tested with employing agency and number of management roles; project-specific management approach response variables (b) tested with managing agency. Number of management roles not tested with project-specific approach variables as this characteristic was specific to managers and would have been replicated by project. Numbers are the coefficients from either Kruskal-Wallis/Mann-Whitney or Pearson’s chi-square tests depending on the type of variable, with all categories included. No significant relationships with Bonferroni adjusted $\alpha=0.003$ and $\alpha=0.006$ for agency and number of management roles, respectively.

<table>
<thead>
<tr>
<th>Management decisions</th>
<th>Manager characteristics</th>
<th>Agency</th>
<th># of management roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) General</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of collaborating groups</td>
<td>10.35</td>
<td>0.04</td>
<td>-0.17</td>
</tr>
<tr>
<td>Number of science collaborators</td>
<td>5.12</td>
<td>0.16</td>
<td>0.050</td>
</tr>
<tr>
<td>Number of researching groups</td>
<td>8.07</td>
<td>0.09</td>
<td>0.086</td>
</tr>
<tr>
<td>Number of information sources</td>
<td>8.34</td>
<td>0.08</td>
<td>0.20</td>
</tr>
<tr>
<td>Monitoring frequency</td>
<td>11.90</td>
<td>0.45</td>
<td>0.42</td>
</tr>
<tr>
<td>Biocontrol</td>
<td>9.20</td>
<td>0.06</td>
<td>-0.090</td>
</tr>
<tr>
<td>Cut-stump</td>
<td>3.29</td>
<td>0.51</td>
<td>0.17</td>
</tr>
<tr>
<td>Heavy machinery</td>
<td>3.91</td>
<td>0.42</td>
<td>0.020</td>
</tr>
<tr>
<td>Burning</td>
<td>7.33</td>
<td>0.12</td>
<td>-0.023</td>
</tr>
<tr>
<td>b) Project-specific</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High priority plants</td>
<td>2.26</td>
<td>0.69</td>
<td>-</td>
</tr>
<tr>
<td>High priority people</td>
<td>10.67</td>
<td>0.03</td>
<td>-</td>
</tr>
<tr>
<td>High priority water</td>
<td>7.36</td>
<td>0.12</td>
<td>-</td>
</tr>
<tr>
<td>High priority wildlife</td>
<td>1.01</td>
<td>0.91</td>
<td>-</td>
</tr>
<tr>
<td>High priority other</td>
<td>4.68</td>
<td>0.32</td>
<td>-</td>
</tr>
<tr>
<td>Highest priority goal</td>
<td>11.25</td>
<td>0.79</td>
<td>-</td>
</tr>
<tr>
<td>Biocontrol</td>
<td>12.46</td>
<td>0.01</td>
<td>-</td>
</tr>
<tr>
<td>Cut-stump</td>
<td>10.36</td>
<td>0.04</td>
<td>-</td>
</tr>
<tr>
<td>Heavy machinery</td>
<td>10.02</td>
<td>0.04</td>
<td>-</td>
</tr>
<tr>
<td>Burning</td>
<td>1.55</td>
<td>0.82</td>
<td>-</td>
</tr>
</tbody>
</table>
In addition to agency, removal method also explained variability in goal prioritization. The proportion of sites with heavy machinery was positively correlated with the priority of plant-related goals (Spearman’s $\rho=0.32$, $df=1$, $p=0.007$; $\alpha=0.008$) and there was a positive trend with wildlife-related goals and heavy machinery ($\rho=0.27$, $df=1$, $p=0.02$) as well as burning ($\rho=0.30$, $df=1$, $p=0.01$; Appendix D, Figure S1.3). Projects
with plant-related or people-related goals as highest priority had the highest proportion of cut-stump both with the project with water as highest priority ($H=13.68$, $df=4$, $p=0.008$; significant with Bonferroni adjustment) and without (Figure 1.5).

![Figure 1.5: Mean (+/- SE) proportion of sites in each project with cut-stump removal of *Tamarix* by which type of goal was assigned highest priority. Water-related goals as highest priority excluded ($n=2$). Pairwise comparisons of means were not significant (Mann-Whitney, Bonferroni adjusted $\alpha$: $p<0.008$). Shown are the significant ($p<0.008$, adjusted alpha) relationships only, so proportions do not add up to 1.]

**Attitude interactions with manager characteristics and decisions**

Attitudes toward science and nature were not significantly associated with characteristics or decisions (Table 1.5). While not significant, there was a trend of an association between relationship with nature and breadth of collaboration. High Guardian values (the attitude that humans have an obligation to take care of nature) tended to be associated with a greater number of collaborating research groups. In addition to collaboration, managers who worked for non-profit organizations or universities tended to have a more integrated science attitude (positive; use more scientific skills and work closely with scientists) than managers employed by a local or state agency (Figure 1.6).
Table 1.5: Relationship between attitudes and manager decisions (top) and between attitudes and manager characteristics (bottom). Numbers shown are coefficients from Spearman’s rho nonparametric regressions and logistic fit, depending on the type of variable. No significant relationships (decisions Bonferroni adjusted $\alpha=0.005$, characteristics $\alpha=0.017$).

<table>
<thead>
<tr>
<th></th>
<th>Science attitude</th>
<th>Developer</th>
<th>Guardian</th>
<th>Spectator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Management decisions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manager decision cluster</td>
<td>0.42 0.51</td>
<td>1.73 0.19</td>
<td>0.94 0.33</td>
<td>3.18 0.08</td>
</tr>
<tr>
<td>Breadth of collaborating groups</td>
<td>-0.17 0.46</td>
<td>0.10 0.66</td>
<td>0.36 0.11</td>
<td>-0.12 0.62</td>
</tr>
<tr>
<td>Breadth of science collaborators</td>
<td>-0.69 0.04</td>
<td>0.034 0.93</td>
<td>0.16 0.68</td>
<td>-0.15 0.70</td>
</tr>
<tr>
<td>Breadth of researching groups</td>
<td>-0.10 0.66</td>
<td>-0.25 0.27</td>
<td>0.57 0.008</td>
<td>0.32 0.15</td>
</tr>
<tr>
<td>Breadth of information sources</td>
<td>0.11 0.64</td>
<td>-0.19 0.41</td>
<td>0.24 0.29</td>
<td>0.080 0.73</td>
</tr>
<tr>
<td>Monitoring frequency</td>
<td>1.24 0.26</td>
<td>0.83 0.36</td>
<td>0.25 0.62</td>
<td>1.06 0.30</td>
</tr>
<tr>
<td>Biocontrol</td>
<td>-0.082 0.72</td>
<td>-0.11 0.63</td>
<td>0.31 0.16</td>
<td>0.027 0.90</td>
</tr>
<tr>
<td>Cut-stump</td>
<td>-0.14 0.54</td>
<td>0.33 0.13</td>
<td>0.19 0.40</td>
<td>-0.099 0.66</td>
</tr>
<tr>
<td>Heavy machinery</td>
<td>0.24 0.28</td>
<td>-0.091 0.69</td>
<td>-0.20 0.38</td>
<td>-0.10 0.65</td>
</tr>
<tr>
<td>Burning</td>
<td>-0.089 0.69</td>
<td>-0.17 0.45</td>
<td>0.26 0.24</td>
<td>0.37 0.09</td>
</tr>
<tr>
<td><strong>Manager characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manager characteristic cluster</td>
<td>0.39 0.53</td>
<td>0.62 0.43</td>
<td>4.56 0.03</td>
<td>0.28 0.60</td>
</tr>
<tr>
<td>Employing agency</td>
<td>8.14 0.04</td>
<td>2.92 0.41</td>
<td>6.10 0.11</td>
<td>1.69 0.64</td>
</tr>
<tr>
<td>Breadth of management roles</td>
<td>-0.24 0.29</td>
<td>-0.28 0.20</td>
<td>0.21 0.34</td>
<td>0.025 0.91</td>
</tr>
</tbody>
</table>
Environment predicts characteristics and decisions

Agencies and types of managers were not distributed randomly or equally between locations in the geographic scope of this study (Table 1.6). The Upper Colorado River Basin (UCRB) had the most privately managed sites. The Lower Colorado River Basin (LCRB) had mostly federally or collaboratively managed sites (Figure 1.2). Federal managers who did not collaborate as much and who did not monitor as widely (M1; Appendix E, Table S1.3) were most common in LCRB while other managers who collaborated and monitored more widely (M2) were most common in the Rio Grande.
Table 1.6: Relationship between location or local conditions and all manager variables. Values shown are Pearson’s chi-square, Spearman’s rho nonparametric regression, logistic fit, or Mann-Whitney coefficients depending on the type of variables. Significant results are bolded (overall cluster $\alpha=0.05$, characteristics Bonferroni adjusted $\alpha=0.017$, decisions Bonferroni adjusted $\alpha=0.004$).

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+ Value from analysis with all categories included
River Basin (GRANDE). Employing agency, management role, all decisions, and attitudes were not significantly different among locations.

Both managers overall (as represented by the cluster group created from all manager variables) and management decisions were related to environmental conditions (Table 1.6). Insular federal managers who used fewer types of monitoring methods (M1) were more frequently found in wetter areas with cooler maximum temperatures (Appendix E, Figure S1.4). For decisions, a high priority of wildlife was most likely utilized in projects with higher temperatures, with a similar but non-significant trend for plant-related goals (Figure 1.7). The highest priority goal was significantly associated with precipitation levels as well as temperature; however, when the project with water-related goals as highest priority was excluded, the highest priority goal assigned was no longer significantly different based on precipitation but was still significantly different.

Figure 1.7: Regression of prioritization of types of goals with normal minimum temperature (average over 30 years, °C), and normal maximum temperature (average over 30 years, °C). Shading indicates confidence interval. Showing significant ($p<0.004$) correlations and trends ($p<0.05$) only.
based on temperature (Figure S1.5) such that wildlife-related goals were more likely to be given highest priority in warmer (or drier) regions. Attitudes toward science and relationship with nature were not significantly related to any environmental variables.

Discussion

This is the first time the relationships among manager characteristics, attitudes, management decisions, and local conditions have been quantified. While there were few significant relationships, I found that agency was the variable most strongly related to management decisions (goals, collaboration, monitoring, information sources, and removal method). Surprisingly, those differences were not strongly indicated by attitudes toward science as reflected in the interviews, which is contrary to the assumption in scientific literature that a positive view of science leads to managers adopting more scientifically recommended management actions. These results reveal the diversity of both types of projects as well as the types of people that work on them, while shedding light on the management implications of these differences.

Manager characteristics explain management decisions

Overall, managing agency (and through association from the project characteristic cluster group, owning agency) had a stronger connection to decision-making than employing agency. Some managers were involved in projects in a consulting capacity, so the employing agency was different from the managing or owning agency. The managing agency will have more say in the detailed operations of removal projects, whereas the manager (if in a consulting capacity and employed by a different agency) may only be
able to make recommendations. Ultimately, the consulting manager has to implement what the managing/owning agency wants. Similar previous findings have shown that stakeholders with a vested interest in restoration outcomes have different project motivations from each other (Hagger et al. 2017), suggesting that the mission of each managing agency (which also has a vested interest) likely also impacts how projects are managed through the prioritization of goals. For example, people-related goals were commonly a high priority for municipalities and local agencies; local agencies tend to be more focused on public use, recreation, and safety, all of which align with the people-related goals of aesthetics, recreation, and wildfire mitigation.

Removal method, on the other hand, may be driven by the resources available to managers rather than the agency itself. Heavy machinery takes very little time but requires the most money to get the equipment and pay someone to run it (Nissen et al. 2010). In the same vein, other methods such as cut-stump require more time and staff to accomplish. Thus, available funding may drive agency decisions to use one method over another (i.e., collaboratively managed projects use slightly less heavy machinery than federally managed) in the same way that monitoring methods have been shown to be driven by resource availability (Kondolf et al. 2007). While the relationship between agency and removal method was not significant, the coding data supported this trend. When asked about whether the removal project was ongoing, one manager said: “we have minimal budgets so we’re always looking for outside funding and that really determines how much [follow-up] work we’re able to do” (Manager 125). While the category of agency does not necessarily indicate the amount of available resources, it can reveal some initial clues to that effect. The size of the agency’s jurisdiction could also have influenced
the amount of biocontrol-only sites. A federal manager may be more likely to have control sites without active removal of tamarisk than a local manager as they have more land to manage and are typically unable to actively remove all tamarisk on their land. Additional qualitative work will be necessary to determine what specific aspects of agencies (e.g., policies, objectives, hiring framework) may be influencing the decision-making processes of land managers.

While there were no significant relationships between characteristics and management decisions, it was not surprising that the cluster grouping for managers’ characteristics was defined by both organization (i.e., agency) and individual traits (i.e., education and experience). As expected, there were likely self-selection pressures and potential hiring aims of the agency that led to this distinction. However, the lack of significant relationships between these characteristics and management decisions was contrary to what the literature suggests. In a previous study with riparian landowners, higher education levels were an indicator for interest in restoration practices (Mojica-Howell and Collins 2012); the same relationship was not evident in this study. In other studies, managers with a higher education level have been found to be more likely to use primary literature and keep up with scientific research (Pardo and Calvo 2006). While the quantitative analyses did not support any of these studies, the coding data did suggest that a higher education level was associated with managers using all available routes of information, that is, the management decision recommended by researchers (such as Sutherland et al. 2004), as demonstrated by one manager with a Ph.D. who called themselves a “sponge to any sort of information out there” (Manager 125). It would be interesting to see in future work if subject area matters, that is, whether a science-based
graduate degree equips managers with scientific skills (i.e., quantifiable goals, question-driven projects, critical thinking) that influence management decisions differently than a graduate degree that is more administrative- or management-based. Many managers with a science-based degree, when asked whether their degree was useful, mentioned that the value of having a science-based degree was the skills they had gained to think critically about restoration actions and design scientifically-sound projects.

Since goals are typically set before removal method is chosen, it is not surprising that the goals prioritized by managers appeared to affect what removal method was used. The association between high wildlife priority and heavy machinery/burning seems counterintuitive as those are the more destructive removal methods and may displace wildlife while they are being done. Invasive riparian plants have been shown to reduce populations and diversity of some native animals (Bateman et al. 2013, Schirmel et al. 2016), so more habitat is quickly opened up when invasive *Tamarix* is dramatically removed using heavy machinery and burning (González et al. 2017c). However, the dramatic removal of *Tamarix* also removes important habitat for native birds (Sogge et al. 2013, Darrah and van Riper 2017), so in this case there may be a disconnect between current research and the management practices being used. In the case of plant- and people-related goals, the selected removal method may have been driven by the goals either to minimize secondary invasions of noxious weeds and protect native plants or to maintain the aesthetics of a site. The coding data support this explanation; for example, one manager talked about using a mulching head to remove tamarisk and said that “with like the public […] as far as the perception, a lot of people expect that you remove the tamarisk and then there’s a beautiful cottonwood gallery the next day and instead of a
bomb-going-off-look to the property” (Manager 106). A study in Europe showed something similar where the general public perceived open areas such as gravel bars to be less aesthetically pleasing than an area with a more developed overstory (Le Lay et al. 2013). Some methods of removal such as heavy machinery can thus be a detriment to recreation efforts.

**Attitude interactions with characteristics and decisions**

The managers I interviewed had a wide range of attitudes toward science on a spectrum from what I have called “integrated” to “polarized” views. Managers with an Integrated view of science looked favorably on the use of science and interactions with science, while managers with a Polarized view used little to no science and were not motivated to incorporate scientific findings into their management processes. This range of views toward science suggests that there is more variability in how heavily scientific skills and information are used by managers than previous studies have indicated (e.g., Bernhardt et al. 2007, Palmer 2009). Regarding relationship with nature, stewardship is most related to my concept of “Guardian” where managers feel the need to take care of nature. As expected, most managers had a relatively high value in the Guardian category and all three nature relationships had a narrower focus around stewardship than nature relationships in the general public (see van den Born et al. 2001) since managers are a very specific subset of individuals who are predisposed to be aligned with the ideals of stewardship (Curtis and de Lacy 1998). However, there was still a range of different relationships; some managers had a more reverent attitude toward nature (“Spectator”) and some had human needs as a top priority over ecosystem needs (“Developer”).
Managers’ relationship with nature was only slightly related to management decisions but not manager characteristics. Managers who felt a desire and responsibility to take care of nature (“Guardian”) tended to work with a wider variety of researching groups; when managers want to take care of nature, they may be more motivated to learn more about the system to figure out the best way to help it through research. Another study also investigated riparian managers’ relationship with nature, but in that study most managers had a perspective similar to my “Guardian” concept, with too little variability to determine differences in decisions (Flieervoet et al. 2013). This is the first study to parse managers’ attitudes in a way that could help explain their decision making, though the relationship is subtle.

Surprisingly, managers who used more science and had an “Integrated” attitude did not make different decisions from managers who used less science. One might expect that “Integrated” managers would be working with more university scientists than any others and would follow more of the recommendations given by scientists, but the data do not support this. There are challenges in determining the details of how managers are collaborating with scientists, as there was no consensus between managers on who a “scientist” is. One manager said that “most of us [managers] are applying, more applied science” (Manager 101) while another manager did not see managers as scientists at all saying that “[we] are just playing loose and fast with science […] and use science but not in a structured or proper way” and their definition of a scientist was “someone who […] is steeped in the formal scientific method” (Manager 109). Another manager mentioned that they “don’t really know what a scientist is” (Manager 106), and Manager 107 considered undergraduate students (in an unspecified subject area) to be scientists. One
said that “you have to ask whether they [Interstate Stream Commission employees] consider themselves scientists or not” (Manager 116). On the other hand, one manager explained “I work on identifying ‘well, who is best equipped to answer that question’ and it might be a university scientist or it might be an agency scientist or a group of scientists or it might be a combination of the two” (Manager 130). Due to the range of interpretations and the inconsistent definition of “scientist” from managers’ perspectives, further study needs to be done on both science-specific collaborations and attitudes toward science using a clearly defined concept of what a scientist is.

Previous findings have suggested that attitudes may not translate directly into actions (Curtis and de Lacy 1998), which my data support. There were no significant relationships between attitudes and management decisions found, likely because managers’ attitudes may be tempered by the missions or needs of the agency they work for. It was, however, surprising that science attitude was not influenced by education as other researchers have found (Pardo and Calvo 2006, Chin et al. 2014). While those managers who worked for a federal agency or a non-profit or university had a slightly more integrated and positive attitude toward science, these two categories of agency were associated with different education levels in the cluster groups (Bachelor’s degree and Masters degree, respectively). A possible explanation for the absence of significant relationships with attitudes could be the limited sample size of managers with attitude data; if more managers were surveyed specifically for attitudes, a stronger pattern may have emerged, but it appears that if they exist, these relationships are subtle at best in this system.
Location and environmental conditions explain characteristics and decisions

Managers’ characteristics and decisions were likely affected by driving forces that were both political and climatic. Agency was not evenly distributed among basins, supporting my hypothesis that there may be political influences in the characteristics of restoration projects. For example, the region near the hydroelectric dams in northern Arizona and southern Nevada is almost entirely federal lands as the federal government has a vested interest in those operations. Alternatively, if projects are within cities, it is more likely that the local public (and thus municipalities or regional agencies) will be invested in restoring urban river reaches as they would use them the most. There were more insular (less collaborative) managers in the Lower Colorado basin, which may be due to geographic isolation; this basin is not as well-populated as the other basins making collaboration more difficult and potentially expensive.

Temperature also most likely influenced managers’ management decisions. In harsh conditions with higher temperatures, wildlife was most important to managers. Wildlife could be more important in warmer regions, as the more southern regions (and thus higher temperature regions) have more critical habitat for endangered birds such as southwestern willow flycatcher (US Fish and Wildlife Service 2013), but this pattern is not visible with the regional distinction of river basin. In the Rio Grande river basin, there is even a federally-mandated partnership (Middle Rio Grande Endangered Species Collaborative Program) that is “specific to those species [southwestern willow flycatcher and silvery minnow], but also specific to doing restoration project to benefit those species, and that started during the last 10-15 years” (Manager 114).
While the attitudes of managers toward nature or science were not predicted by location or environmental conditions, I did see in the interviews that there were more managers who saw the need to develop nature (“Developer”) in New Mexico, likely a reflection of the intense engineering (i.e., levees, jetty-jacks, swales) of the riparian system. As described by Manager 114: “We did high flow channels and swales, but again, folks at the time were sort of hesitant to remove jacks from the bank line, you know, worried about the river getting out of the banks and flood control and that kind of stuff.” Manager 116 also mentioned the engineering aspect: “they’re opening up places that used to be sandbars so a river could flow there and putting them right next to some of the picnic areas which is really cool because it’s going to get people to go out there.” While not statistically significant, there were more managers who saw themselves as a smaller part of nature as a whole (“Spectator”) in the Upper Colorado basin, possibly due to conflict between recreation and restoration efforts. Manager 124 said “recreation has exploded and it kind of seems like a lot of areas get trampled and taken over by recreation.” Manager 128 expanded on this idea: “recreation has always been an issue here but it’s shifted in the last few years to it is the issue here now.” However, this result may be biased by the relatively small sample size of the attitude data.

Conclusion

Since the 1990s there has been a substantial increase in the number of publications on riparian restoration (Sher 2013, González et al. 2015), but few have quantified the dynamics of what drives the actions of these managers rather than just describing management decisions. My study is the first comprehensive exploration of
what drives the management decisions of land managers based on their own traits and environmental conditions at their sites, which is critically important to understand in restoration projects. Even given the reduced analytical power due to the large number of tests conducted, these results show that the traits (i.e., agency and attitudes) of managers and geographic locations of their projects may affect their behavior in the form of the management decisions. My analysis supports the idea that managers are taking the time to prioritize goals based on what is feasible (both logistically and ecologically), that is, they are following place-based goal prioritization consistent with recommendations from researchers (e.g., Shafroth et al. 2008, Palmer 2009, González et al. 2017a). Since agency was the most important manager trait in explaining management decisions, improvement in restoration practices may need to be made on the larger agency-level rather than individual managers, just as the entire socio-ecological system needs to be targeted in restoration projects and not just the physical riparian system alone (Palmer 2009). Future work can expand upon these results by exploring potential indirect impacts of the traits and behaviors of managers on the ecological system, in order to better understand what contributes to a more successful project.
CHAPTER TWO: INDIRECT EFFECTS OF MANAGERS ON VEGETATION COMMUNITY FOLLOWING RESTORATION

Introduction

Most studies on the ecological outcomes of restoration investigate direct actions on ecosystems, such as methods used to actively remove invasive plant species (Ruiz-Jaen and Aide 2005, González et al. 2015), but a growing body of literature suggests that traits of land managers and the decisions (exclusive of direct actions) they make may also be indirectly important in predicting ecological outcomes of restoration (Wortley et al. 2013, Morandi et al. 2014). These characteristics of managers and management decisions have been frequently highlighted for managers by scientists, but only some recommendations related to direct and active restoration measures have been corroborated with ecological data (see González et al. 2017c, 2017d). Here, I test for the first time other common recommendations associated with indirect measures such as where managers get their information from and who they work with. In much the same way that organisms may have indirect effects on one another (e.g., Jones et al. 1994, Knight et al. 2006, Bennett et al. 2011), managers’ characteristics may indirectly impact ecological outcomes through the direct restoration actions they choose to take. The most commonly recommended management decisions such as choosing and prioritizing management goals (e.g., González et al. 2017a), type and degree of collaboration (e.g., Bernhardt et al. 2007), what information sources are used (e.g., Sutherland et al. 2004),
and monitoring choices (e.g., England et al. 2008) may also indirectly impact ecological outcomes in much the same way. And just as previous research has shown that managers’ views on science and their relationship with nature can predict general management decisions (i.e., collaboration, Chapter 1), those same views may also affect direct restoration actions and in turn affect outcomes. In this study, I quantify for the first time the relationship between each of these three categories (manager characteristics, management decisions, and manager attitudes) and the resulting vegetation after restoration, and consider potential obstacles to restoration success as determined by the managers themselves.

There are few existing studies in restoration ecology on the potential indirect effects of managers’ characteristics on restoration outcomes, so here I consider four of the most common characteristics mentioned in the literature: agency (i.e., governing body or organization), management role, experience in land management, and education level. Morandi and others (2014) found that the involvement of agencies or institutions in restoration was variable such that some agencies were more likely to be involved in the implementation of restoration efforts than others. Furthermore, managers who have more experience and thus understand the subtleties specific to the system they work in most likely use restoration practices that they know have worked in the past (Wallington et al. 2005). Finally, managers with a higher education level are expected to follow scientific recommendations (as in Sutherland et al. 2004, Sher et al. 2010), though one study suggests that this may not be the case (see Chapter 1). Here I test the prediction that managers with both a higher education and more experience have the most desirable outcomes (e.g., more native than exotic plants) in their restoration projects.
In addition to manager characteristics, I also tested the indirect effects of the three most important recommended general management decisions from researchers on restoration outcomes. The first management decision considered here concerns restoration goals. Many studies emphasize the importance of goals (i.e., general management objectives), both for selecting management strategies and for project assessment (e.g., Shafroth et al. 2008, Nilsson et al. 2016, González et al. 2017a). Some researchers recommend that the prioritization of goals be evidence-based and tailored to each site (Palmer 2009). Thus, if goals are important to restoration outcomes, I expect to see a difference in resulting vegetation based on what goals have been deemed important by managers. For example, if managers prioritize plant communities (i.e., native plant diversity and/or exotic plant removal) over the needs of people or wildlife, their sites might have a high level of nativity after restoration. The second recommended but untested general management decision is collaboration both with other managers and with researchers. Collaboration can increase the scale of restoration projects such that the entire watershed can be targeted rather than a small piece (as in Oppenheimer et al. 2015), allows managers to pool limited resources (as in Fliervoet et al. 2013), and gives managers the opportunity to learn from others’ mistakes (Bernhardt et al. 2007). Scientists have also recommended that managers supplement collaboration with evidence-based sources (Sutherland et al. 2004). If these recommendations improve restoration efforts when implemented, managers who collaborate more and use a wide range of information sources will be expected to have better restoration outcomes. Finally, comprehensive and frequent monitoring are highly recommended in the literature (e.g. Palmer et al. 2005, Sher et al. 2010); while monitoring itself provides the data used
to determine outcomes of restoration projects, the possible indirect effects of the breadth and frequency of monitoring have yet to be quantified. Monitoring is seen by many researchers as critical for successful outcomes (e.g., Holling and Meffet 1996, Bash and Ryan 2002, England et al. 2008) and with comprehensive monitoring efforts, managers can have a clearer interpretation of a “successful” project (Bernhardt et al. 2007). With monitoring, follow-up actions are expected to be taken more accurately based on the conditions of each site, i.e., adaptive management (Noss 1990). Ecological data has not yet been used to corroborate these three assumptions in the literature, which I have done in this study.

Restoration outcomes may also be impacted indirectly by managers’ attitudes – specifically toward science and nature. In the previously mentioned management recommendations, an underlying pattern is evident: the importance of the integration of science into restoration projects (e.g., Palmer 2009, Stromberg et al. 2009, Sayre et al. 2013). The possible impacts of this assumption are two-fold. First, if managers integrate scientific information, they may better understand the conditions and potential for recovery at each site. And second, managers who have a favorable attitude toward science may be more likely to work with scientists and use scientific skills to be able to adapt their restoration approach based on current findings. Thus, managers with a more positive attitude toward science who use more science in their decision-making are expected to have sites with more desirable plant communities.

Another potentially important aspect of manager attitudes is how they view their relationship with nature. In Chapter 1, managers had a range of relationships with nature that were all aligned – to varying degrees – with the ideals of stewardship, where humans
take care of nature for future generations. This corroborates findings by Curtis and de Lacy (1998), who found that rural managers in Australia followed a strong stewardship ethic overall. However, it is possible that managers who are more economically-driven may be more focused on “command and control” actions for invasive plant management rather than retaining ecosystem resilience, ultimately resulting in a more weedy plant community composition as weedy invasives can have a positive effect on resilience (Holling and Meffet 1996). On the other hand, managers with a more hands-off approach due to the belief that nature has the ability to heal itself may use more passive actions such as restoring natural disturbance systems such as stream flows to address the root-cause, which then may result in more mesic sites (as suggested by Stromberg 2001, Shafroth et al. 2008).

Finally, it is important to also gain the perspectives of the managers on what can influence the success of projects using a standardized measure of restoration outcomes – as opposed to each individual manager’s definition of “success” – rather than relying solely on the outside perspectives of researchers. According to previous studies, the success of projects was frequently anecdotal (Kondolf et al. 2007) and the definition of “success” can potentially be different from person to person (Hagger et al. 2017). Bernhardt and others (2007) found that the majority of riparian managers across the US subjectively viewed their projects as “successful”, and while their success was not corroborated with ecological data, the more “successful” projects had heavy community involvement and were more likely to have an advisory committee. In the same study, it was found that both social and organizational factors were considered to determine success along with ecological factors. If the perspectives of managers are considered in
the context of a standardized measure of ecological success (as separate from social and organizational success), patterns may emerge to give insight into particular actions that lead to success or specific barriers in restoration projects.

I used vegetation data from riparian restoration projects across the Southwest US to test the indirect effects of manager characteristics, decisions, and attitudes on restored ecosystems. The health of riparian systems in this region has been in decline in the recent past due to particularly threatening anthropogenic pressures including the introduction of invasive species such as the shrubby invasive tree *Tamarix sp.* (tamarisk, saltcedar; González et al. 2017a); a common practice in riparian restoration in the Southwest US is the removal of this widespread tree (Briggs et al. 1994, Stromberg et al. 2007). A previous study revealed that the method managers used to remove *Tamarix* affected the vegetation community; sites with only biocontrol via *Diorhabda* beetles had more *Tamarix* abundance, while heavy machinery and cut-stump removal (individual trees are cut down then sprayed with herbicide) yielded more native plant communities (González et al. 2017c). However, there is still some unexplained variability in the success of *Tamarix* removal projects, and there are likely more factors – which are subject to change based on indirect actions – that directly influence the plant community than just removal method, such as the way the chosen removal method is performed and other, more subtle factors. The characteristics and decisions of managers that I have measured help to predict not only the effects of major actions (i.e., removal method) on ecosystems (see Chapter 1), but also the subtle actions and effects. In this project, I test the following four questions: 1) which manager characteristics are related to plant community composition after restoration, 2) which general management decisions are related to plant community
composition after restoration, 3) do the attitudes of managers toward science or nature impact resulting plant community composition after restoration, and 4) are there common actions taken or challenges faced by managers with similar plant communities in their sites? None of these relationships have yet been tested with ecological data, as I have done here, in order to better determine what recommendations lead to better restoration outcomes and are thus worth the effort and resources managers require to use them.

**Methods**

*Vegetation Data*

Using a large dataset compiled by González and collaborators (2017), I identified land managers of 244 *Tamarix* removal sites (see Chapter 1). These sites are distributed across the Upper Colorado, Lower Colorado, and Rio Grande river basins in the southwest US and encompass lands owned by a variety of public and private management agencies (see Figure 1.2). From this dataset, I used vegetation data to better understand how managers may influence restoration outcomes. Species abundance data was collected by collaborators in the field between 2003 and 2014. In collaboration with Dr. E. González at Colorado State University, a principal component analysis (PCA) was performed on the Hellinger transformed (Legendre and Gallagher 2001) abundance data, which summarized the plant communities on four axes (principal components, Figure 2.1). Principal component analysis uses multiple variables to create a smaller number of new values along vectors that maximize the variation in the data (Ringnér 2008). Cumulatively, the first four axes explained 38% of the variability in plant community composition. Principal component 1 (PC1, “overstory”) was primarily driven by overstory composition, PC2 (“nativity”) was driven by exotic and native plant species,
PC3 ("weeds") was driven by the type of plant invasion (i.e., primary or secondary), and PC4 ("upland") was driven by the relative abundance of hydrophytic species. In this study, the site scores of the removal sites for these four axes were used as the response variables for all analyses to utilize the full power of the database.

Land manager data

Managers were defined as individuals who made management decisions – including job titles such as restoration ecologist, wildlife biologist, hydrologist, program manager, planner, or superintendent – on projects. A project was defined as one or more sites with the same managing and owning agency and restoration objectives. Only the data from primary managers was used for this study (see Chapter 1 for explanation of “primary manager” and total numbers), as over half of all projects (54 out of 80 total) had multiple managers. A total of 31 primary managers completed the survey, encompassing 46 projects (227 sites or 93% of the sites in the original dataset). Of the 31 managers, 18 were interviewed in addition to taking the survey; 5 interviews were also conducted with...
non-primary managers that were not used for quantitative analyses to avoid site replication. The full sample of 31 primary managers (46 projects) was used for all characteristic and decision variable analyses, while only data from the 18 interviewed primary managers were used for attitude analyses. All 23 interviews – including non-primary managers – were included in qualitative analyses as additional perspectives for the same projects were still useful and gave more insight into collaboration between managers.

Survey data

The survey – administered online through Qualtrics (for full survey and administration methods, see Chapter 1 and Appendix A) – covered two main topics: manager characteristics and management decisions. Characteristics were defined as the underlying traits that described the managers. The four specific manager characteristic variables covered agency (1-3) and management role (4; Table 2.1):

Agency. Employing agency was designated to each manager (5 categories: private, non-profit/university, local, state, and federal), while managing agency was specific to each project. Five similar categories were created for managing agency: private or non-profit or local (including municipal and county), state, federal, and collaborative (more than one agency). There was only one project managed only by a local agency, so that category was lumped with private/non-profit as both local and private/non-profit agencies have a similar size and scope relative to state or federal agencies. Owning agency was previously found to be closely associated with managing agency (see Chapter 1), so only managing agency was considered individually here. However, the owning and managing
Table 2.1: Relationship between project and manager characteristics and plant community composition, as defined by each of four principal components. Shown is the coefficient from a mixed model; project was the random effect for project-specific variables (2 and 3), and manager was the random effect for the others (1 and 4). Number of management roles shows the coefficient from Spearman’s rho non-parametric regression as it was the only continuous variable. Bolded text shows significant relationships (Bonferroni adjusted α: *p*<0.013).

<table>
<thead>
<tr>
<th>Manager characteristics</th>
<th>Overstory (PC1)</th>
<th>Nativity (PC2)</th>
<th>Weeds (PC3)</th>
<th>Upland (PC4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>coefficient</td>
<td><em>p</em>-value</td>
<td>coefficient</td>
<td><em>p</em>-value</td>
</tr>
<tr>
<td>Agency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Employing agency</td>
<td>3.58</td>
<td>0.03</td>
<td>0.35</td>
<td>0.79</td>
</tr>
<tr>
<td>2) Managing agency*</td>
<td>3.68</td>
<td>0.02</td>
<td>3.70</td>
<td>0.02</td>
</tr>
<tr>
<td>3) Same managing and owning agency?*</td>
<td>8.71</td>
<td>0.005</td>
<td>5.63</td>
<td>0.02</td>
</tr>
<tr>
<td>Role</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) Number of management roles</td>
<td>-0.05</td>
<td>0.46</td>
<td>-0.21</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Project-specific variable

+All categories included in analysis
agency were not always the same, so a variable was included to test the possible effect of this on vegetation outcomes. In Chapter 1, experience and education were found to be confounded with employing agency (more experienced managers with a Bachelor’s degree worked mostly for federal agencies; see Table 1.3) so only employing agency was considered individually here.

Management role. Role was the only continuous categorical variable, which was recorded as the number of roles undertaken by each manager in all projects.

Management decisions were considered to be the action(s) the manager chose to take in their restoration projects. The 11 specific management decision variables covered the priority of goals for each project (1-6), collaboration and information sources (7-10), and monitoring (11; Table 2.2):

Goal prioritization. I combined project goals into five groups based on similarity: plant-related, people-related, water-related, wildlife-related, and other goals (see Table 1.2). Variables 1-5 are continuous and represent the degree of importance for each group. Variable 6 is categorical, representing what group of goals was the highest priority of all five groups for each project.

Collaboration and information. I recorded the multiple choice responses for collaboration and number of information sources as a count to represent breadth (see Chapter 1 for details). Collaboration included what groups managers collaborated with in general, for research, and with scientific groups specifically. In Chapter 1, the type of information source and monitoring collaborations were confounded with the number of general collaborating groups (mixed sources and more monitoring collaboration with more
Table 2.2: Relationship between management decisions and plant community composition. Categorical variables (highest priority goal and monitoring frequency) show the coefficient from a mixed model with project (highest priority goal) or manager as random effect; all other variables show the coefficient from Spearman’s rho non-parametric regression. Bolded text shows significant relationships (Bonferroni adjusted \( \alpha: p<0.013 \)).

<table>
<thead>
<tr>
<th>Management decisions</th>
<th>Overstory (PC1) coefficient</th>
<th>Overstory (PC1) p-value</th>
<th>Nativity (PC2) coefficient</th>
<th>Nativity (PC2) p-value</th>
<th>Weeds (PC3) coefficient</th>
<th>Weeds (PC3) p-value</th>
<th>Upland (PC4) coefficient</th>
<th>Upland (PC4) p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal prioritization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) High priority plants*</td>
<td>0.16</td>
<td>0.02</td>
<td>0.18</td>
<td>0.007</td>
<td>-0.07</td>
<td>0.33</td>
<td>0.12</td>
<td>0.07</td>
</tr>
<tr>
<td>2) High priority people*</td>
<td>-0.006</td>
<td>0.93</td>
<td>-0.36</td>
<td>&lt;0.001</td>
<td>0.09</td>
<td>0.17</td>
<td>-0.19</td>
<td>0.004</td>
</tr>
<tr>
<td>3) High priority water*</td>
<td>0.23</td>
<td>&lt;0.001</td>
<td>0.29</td>
<td>&lt;0.001</td>
<td>-0.07</td>
<td>0.31</td>
<td>0.19</td>
<td>0.005</td>
</tr>
<tr>
<td>4) High priority wildlife*</td>
<td>0.23</td>
<td>&lt;0.001</td>
<td>-0.03</td>
<td>0.70</td>
<td>0.005</td>
<td>0.94</td>
<td>0.08</td>
<td>0.25</td>
</tr>
<tr>
<td>5) High priority other*</td>
<td>-0.16</td>
<td>0.02</td>
<td>-0.15</td>
<td>0.03</td>
<td>0.09</td>
<td>0.19</td>
<td>-0.03</td>
<td>0.64</td>
</tr>
<tr>
<td>6) Highest priority goal*</td>
<td>0.27</td>
<td>0.90</td>
<td>1.01</td>
<td>0.41</td>
<td>0.75</td>
<td>0.56</td>
<td>0.22</td>
<td>0.93</td>
</tr>
<tr>
<td>Collaboration and information</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7) Number of collaborating groups</td>
<td>0.05</td>
<td>0.44</td>
<td>0.19</td>
<td>0.004</td>
<td>-0.17</td>
<td>0.01</td>
<td>-0.10</td>
<td>0.13</td>
</tr>
<tr>
<td>8) Number of science collaborators</td>
<td>-0.18</td>
<td>0.15</td>
<td>-0.36</td>
<td>0.003</td>
<td>0.06</td>
<td>0.63</td>
<td>-0.09</td>
<td>0.45</td>
</tr>
<tr>
<td>9) Number of researching groups</td>
<td>0.20</td>
<td>0.003</td>
<td>0.34</td>
<td>&lt;0.001</td>
<td>-0.18</td>
<td>0.006</td>
<td>0.32</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>10) Number of information sources</td>
<td>0.43</td>
<td>&lt;0.001</td>
<td>0.20</td>
<td>0.003</td>
<td>0.07</td>
<td>0.31</td>
<td>0.32</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11) Monitoring frequency</td>
<td>0.24</td>
<td>0.87</td>
<td>1.13</td>
<td>0.35</td>
<td>0.76</td>
<td>0.53</td>
<td>0.90</td>
<td>0.45</td>
</tr>
</tbody>
</table>

*Project-specific management decision
general collaboration; see Table 1.3 and 1.4) so only the variable for general collaboration was considered individually here.

Monitoring. I asked managers how frequently each method of monitoring (i.e., visual, biological, physical, or chemical) was used, so the overall monitoring frequency was recorded as the highest frequency for any method used. The type of monitoring method was found in Chapter 1 to be confounded with the number of general collaborating groups (more methods with more general collaboration; see Table 1.3 and 1.4), so monitoring method was not tested here.

Interviews

I designed the interviews as a follow-up and supplement to the survey (for more details on interviewing methods, see Chapter 1 and Appendix A). The iterative coding of the interviews – where codes (phrases tagged with a specific idea or attitude) were organized based on similarity in themes (Auerbach and Silverstein 2003, Saldaña 2009) – resulted in seven distinct themes in addition to the attitude-specific codes related to science and relationship with nature. A comprehensive list of codes and the associated themes are located in Appendix D.

I defined two distinct attitudes toward science that emerged from the data: Polarized and Integrated (see Appendix C, Figure S1.1). For both groups, I weighted specific codes then assigned negative (polarized) or positive (integrated) values (see Chapter 1 and Appendix C). The codes were then added together so that a positive value indicated a more integrated attitude and a negative value indicated a more polarized attitude toward science.
To test whether managers’ relationship with nature can explain plant community composition, I assessed relationship with nature by coding statements made by managers in the interviews (loosely based on de Groot et al. 2011, see Chapter 1 for details). I sorted these codes into three different categories to represent attitudes: Developer (1), Guardian (2), and Spectator (3, see Appendix C). Developer is loosely related to the “master” relationship (sensu de Groot et al. 2011) where humans are above nature and restoration actions are undertaken (frequently using a lot of technology) for the ultimate benefit of people. Guardian is similar to the “stewardship” and “partner” relationship where humans and nature are equal, and managers want to take care of nature so that it will be there for future generations; Spectator is most similar to the “participant” relationship with humans as a small and insignificant part of nature (sensu van den Born et al. 2001, de Groot et al. 2011). Managers did not tend to adhere to only one relationship category, so I determined the degree to which managers aligned with each attitude by calculating for each manager the proportion of codes in each category by the total number of codes (in any subject) for that manager. The value for each relationship represented how important that attitude was for each manager overall. I used nonparametric Spearman’s rho regressions to test the influence of attitudes on plant community composition.

Analysis of survey data

To investigate whether managers as a whole can predict plant community composition, I first classified managers based on characteristics and management decisions using a cluster analysis (with assistance from Dr. González). The clusters were
made in R 3.4.1 (R Core Team 2017) using partitioning around medioids (PAM method, Kaufman and Rosseeuw 1990) where the number of clusters is estimated by the optimum average silhouette width using the function pamk of the package fpc (Henning 2015). Gower distances (Gower 1971, Legendre and Legendre 2012) were used with the function daisy of the package cluster (Maechler et al 2017). I then characterized the cluster groups by comparing significant differences in responses between groups using Pearson’s chi-square and Mann-Whitney analyses for categorical and continuous response variables, respectively (Appendix E, Table S1.3).

To determine whether individual traits of or decisions made by a manager can explain plant community, I used vegetation composition as a whole as represented by the four PC axes. In addition to the 244 removal sites, there were also 172 reference sites in the dataset, and some (but not all) projects had data before and after removal with multiple observations (see González et al. 2017c, 2017d). All observations and reference sites were used for the principal component analysis to utilize the full power of the database. I used species-specific metrics such as total native plant cover and Tamarix cover in preliminary explorations of the data but they yielded very few significant relationships, suggesting that they were not meaningful. In using the PC axes, I was able to use all of the vegetation data and allow the data itself to define the dependent variables that represented plant community. I used manager characteristics, decisions, and attitudes as independent variables. As in Chapter 1, the data were organized in three different levels: site, project, and manager (see star schema of the data in Figure 1.3); each manager had one or more projects and each project had one or more sites. To account for pseudoreplication across levels, I used mixed models for all categorical independent
variables for both characteristics and decisions, with project (for local experience, managing agency, owning agency, and highest priority goal) or manager (for all other categorical variables) as the random effect (see Table 1.1 for comprehensive variable list). I applied a Bonferroni adjusted alpha (0.013) to all tests as there were four tests for each independent variable. To test the relationship between the continuous human variables and plant community composition, I used Spearman’s rho non-parametric regressions. However, Spearman’s rho tests do not have a mechanism to correct for pseudoreplication and there are few mixed models that can account for the complex organization and non-normal distribution of the data. As these relationships have never been tested before, I chose to use the regressions to indicate which variables should be researched further, so the significance of results was likely inflated, increasing the risk of a Type I error. In future analyses, I will be doing complex mixed models using smoothing splines with these data to account for pseudoreplication effects.

**Qualitative assessment**

To investigate the management similarities and differences among projects with similar plant community composition, I explored all categories of codes (e.g., public relations, collaboration; “themes”; see Appendix D, Table S2.1 for full code list) qualitatively in the context of whether the actual plant communities were desirable or not at each site to investigate further the possible influence of managers on vegetation composition. For these sites, the most desirable state was considered a more native cottonwood gallery forest (*sensu* González et al. 2017); a more mesic plant community was also desirable, though was not given as much weight as sites may be influenced by
“terrestrialization” (a shift from mesic to xeric) from bed degradation (Dixon et al. 2012), which in most cases was out of the scope of projects designed specifically for *Tamarix* removal as remediation may require region-wide changes such as environmental flows, change of land use in the watershed, etc. While the PC vector representing weeds (PC3) was important for describing the plant community, neither primary invaders nor secondary invaders are considered “desirable,” so that metric was not included in the assessment. I grouped the managers into three categories: those corresponding to least desirable (lowest values for overstory [PC1] and nativity [PC2] PC vectors, highest value for upland [PC4] PC vector), moderately desirable, and most desirable (highest values for overstory and nativity, lowest value for upland). In this way, I was able to determine both the challenges associated with managing sites with the least desirable plant communities as well as actions or attitudes that may be associated with more desirable outcomes to give a deeper understanding of the interactions between humans and ecosystems.

**Results and Discussion**

Vegetation composition of *Tamarix* removal sites (as defined by up to four principal component vectors) was associated with the characteristics, decisions, and to a lesser degree, attitudes of the managers responsible for the projects as well as the management decisions they made. Many claims have been made for what indirect aspects of management decisions (e.g., collaboration, monitoring, etc.) are the most influential in restoration projects, but to my knowledge this is the first time those claims have been tested with ecological data. In this study, collaboration was the most important decision, evident in the relationship with vegetation composition and agency, role, importance of
goals, information sources used, and the specific collaboration variables. Overall, the type of manager may have affected plant community composition: federal managers that did not collaborate or monitor widely (i.e., less groups or less types, respectively; Cluster Group 1; Appendix E, Table S1.3) had sites with a less desirable plant community (upland Tamarix monoculture) than managers from other agencies who monitor and collaborate more (Cluster Group 2, Figure S2.1), which also suggests that agency, collaboration, and monitoring may all have indirect effects on plant communities following restoration.

Manager characteristics

Among manager characteristics, both agency and number of management roles explained plant community composition. Different agencies may own or manage the same site, and the plant community was more desirable (as characterized by a cottonwood overstory and less exotics and weeds) on sites with different agencies rather than the same agency in those roles (Table 2.1, Figure 2.2). When the managing and owning agency were different, the most common combination was a local or federal owning agency with collaborative management (i.e., more than one agency; see Appendix E, Figure S2.2).

These results suggest that collaboration between the agencies enhanced the projects (also demonstrated by Oppenheimer et al. 2015). One manager said: “I think that having multiple agencies is always beneficial just like from the different viewpoints and each agency has different protocols that they use […] and different reporting requirements which sometimes feels like you’re getting bogged down […] but I think it
actually ends up being really cool, because then you learn more things like about going through the different [...] policies of like the BLM versus the Park service and like navigating through that and making sure that you’re compliant with all their standards, I think ends up being a more robust project in the end” (Manager 124). The roles of managing and employing agency also had different slight associations with vegetation (Appendix E, Figure S2.3 & S2.4), which also supports the idea that collaboration is beneficial as each agency may influence projects in different ways, related to their mission or available resources.

Management role also predicted site scores for three of the four principal component vectors for plant community composition, such that the more roles managers had, the worse condition the plant community was in (i.e., more exotics and weeds; Table 2.1; Appendix E, Figure S2.5). This was a surprising result as number of roles did not
predict management decisions (Chapter 1), and suggests that the number of roles is correlated with some other manager characteristic or decision that was not measured, such as available resources or time investments. For example, managers may have more roles when the plant community is not favorable because they need to invest more time and/or energy into restoring the sites. On the other hand, if managers are trying to take on more roles, they may try to do more than they are capable of doing with their available resources. One manager who had many management roles including being the primary decision maker said: “sometimes we made that mistake […] where we bit off more than we could handle as far as ‘we’ve got this big crew let’s do all this stuff,’ and the next year it’s like, ‘we didn’t get to it all.’ I lost some areas we invested in because I just couldn’t keep up. […] That’s burned us more than once where we had an opportunity to do a lot and we took it but the follow-up wasn’t there and we ended up kind of wasting some effort” (Manager 131). While it was not evident in quantitative comparisons of number of roles and breadth of collaboration (see Chapter 1), this result also suggests that collaboration may help managers to mitigate the issues that come from having too much to do and not enough time to do it.

Management decisions

Management decisions also explained plant community composition as represented by principal component vectors. As expected, the prioritization of goals was an important management decision for explaining the plant community composition (Table 2.2). Figure 2.3 shows correlations between the importance of each type of goal and each relevant PC vector for plant community; the sites scores are from a negative to a
positive value, so when reading the graph, if the trend line is in the bottom half below the dotted line (representing zero), the plant community is dominated by more riparian and exotic species with more *Tamarix* monoculture but more primary invaders. If the trend line is in the top half of the graph, the plant community is dominated by more upland, native species with more cottonwood forest but more secondary invaders. Therefore, the sites with the most desirable plant communities had a high priority of water-related goals (more upland, native cottonwood forests; Figure 2.3a) as well as plant- and wildlife-related goals (dominated by cottonwood; Figure 2.3b, c), whereas a higher priority of people-related goals was associated with more mesic and less desirable exotic plant communities (Figure 2.3d).

How goals were prioritized by managers appears to have had an indirect effect on the resulting plant community. In previous research, the priority of goals has been shown to be correlated with *Tamarix* removal method (Chapter 1), but goals likely influence other management decisions as well. Plant-, wildlife-, and water-related goals were associated with similar plant communities which align more closely with outcomes which are considered to be more “desirable” or “successful” in restoration studies. This result suggests that these managers are following recommendations from scientists, and may also be designing their projects based on the existing plant community. For example, if a site was more xeric-adapted, managers may have been more likely to prioritize floodplain connectivity or restoring flows to return it to an historic, mesic state (Rohde et al. 2005, González et al. 2017b). Additionally, managers who were specifically concerned about endangered birds (i.e., southwestern willow flycatcher) tended to target the overstory specifically and more carefully, but they may have also selected sites particularly suited
Figure 2.3: Regressions of plant community composition by the priority of types of goals: a) water-related goals, b) plant-related goals, c) wildlife-related goals, and d) people-related goals. Plant community metrics are Principal Component axes created from all vegetation abundance data (800 observations). Shading indicates confidence interval. Shown are significant correlations (Bonferroni adjusted $\alpha$: $p<0.013$) or marginally significant correlations from Spearman’s rho regressions only.
for habitat that already had a more developed overstory or a mixed stand (as suggested by Hultine et al. 2010).

On the other hand, when people were a higher priority, managers seemed to be oriented toward what people expect or want to see such as more open space along a river (as suggested by Le Lay et al. 2013), regardless of whether the remaining species are native or exotic. This idea of a disconnect between what the public want and ecologically desirable plant communities was corroborated by a study done in Belgium where horticulturalists – who reflect the desires of the general public through what they can sell – were less concerned about exotic plant species than reserve managers due to a lack of information (Vanderhoeven et al. 2011). This dichotomy between anthropocentric versus ecocentric goals suggests that one of the benefits of collaboration may be to reconcile the two types of goals and make projects more robust, as previously mentioned by Manager 124.

The management decision of whether to collaborate (both with information sources used and with all collaboration variables) also explained some portion of plant community as represented by PC vectors (Table 2.2). When more information sources were used by managers, the plant community was more desirable as characterized by a more upland, native, cottonwood forest (Appendix E, Figure S2.6), as expected. This result suggests that a wider knowledge base is important (as recommended by Sutherland et al. 2004) and that managers might benefit from gathering information from as many sources as possible, regardless of the format (e.g., presentations, published materials, conversations) and sometimes through collaborations. This explanation is also supported by the previous finding that managers who collaborate with more groups in general also
tend to use a mix of different types of information sources (i.e., formal or informal; Chapter 1), suggesting that a mix of information types would also be associated with more natives and less weeds. When asked what sources were most influential in decision-making, one manager said that “when you’re talking with a person who has actual experience in the field, it doesn’t matter to me if they’re a cowboy or a rancher or academia, if they’ve done it and worked on it, you can learn stuff from everybody, some if it’s good, some of it’s not” (Manager 104) and another manager when asked whether formally published sources were more important than face-to-face interactions said “I’m just a sponge to any sort of information out there. […] I need both; I don’t know” (Manager 125).

The most desirable plant communities were in sites managed by individuals who collaborated with more groups in general (more natives and less weeds, Figure 2.4a) and specifically for research (upland, native cottonwood forest with less weeds, Figure 2.4b), which corroborates the assumption that collaboration is important to the success of restoration projects (Bernhardt et al. 2007, Fliervoet et al. 2013). However, contrary to my predictions, the plant communities associated with more exotics were related to managers who collaborated with more science-specific groups (Figure 2.4c). A possible explanation for this correlation may be that managers who have sites in worse condition may need additional help outside of land management networks, so may seek out collaborations with scientists.

Previous research has also shown that managers who collaborate with more groups in general also use a wider variety of monitoring methods (i.e., visual, biological, chemical, or physical; Chapter 1), so more methods may also be associated with more
Figure 2.4: Regressions of plant community composition by collaboration: a) number of general collaborating groups, b) number of collaborating groups conducting research, and c) number of science collaborating groups. Plant community metrics are principal component axes created from all vegetation abundance data (800 observations). Shading indicates confidence interval.Shown are significant ($p<0.013$) correlations from Spearman’s rho regressions only.
natives and less weeds. There are a couple of possible explanations for this association. The first is that it may be easier to plan and conduct follow-up treatments of exotic re-growth if managers are using more monitoring methods and thus visiting more often, as was mentioned by Noss (1990). The frequency of monitoring did not predict plant community, however, so a more detailed measure of monitoring frequency may need to be used to detect any relationships with vegetation community in future studies. On the other hand, when a site is dominated by more natives, managers may be able to devote more resources into monitoring other aspects of the site besides plant inventories (i.e., biological methods) such as water quality (i.e., chemical methods) or soil conditions (i.e., physical methods).

Manager attitudes

Attitudes of managers did explain some of the variability in plant community composition (Table 2.3), however not in the directions I expected. The most pervasive assumption in the literature was the idea that managers who looked more favorably on the use of science and interactions with scientists are expected to have better outcomes, so it was surprising that attitude toward science, as reflected by the interviews, was not related to outcomes in my study. There was, however, a trend of managers who used more scientific skills and viewed science in a positive light (“Integrated” attitude toward science) having more upland sites. It is possible that those managers who were more connected to the science community and knew the current research understood that changing sites from xeric back to mesic was not practical on smaller scales as the root cause of modified flows (i.e., dams or diversions, irrigation, etc.) would need to be addressed (Briggs et al. 1994, Stromberg et al. 1996, Stromberg 2001). One manager with
Table 2.3: Relationship between manager attitudes and plant community composition. Coefficients from Spearman’s rho non-parametric regression. Bolded text are significant relationships ($p<0.013$).

<table>
<thead>
<tr>
<th>Manager attitudes</th>
<th>Overstory (PC1) coefficient</th>
<th>Overstory (PC1) p-value</th>
<th>Nativity (PC2) coefficient</th>
<th>Nativity (PC2) p-value</th>
<th>Weeds (PC3) coefficient</th>
<th>Weeds (PC3) p-value</th>
<th>Upland (PC4) coefficient</th>
<th>Upland (PC4) p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science attitude</td>
<td>-0.05</td>
<td>0.54</td>
<td>0.06</td>
<td>0.49</td>
<td>0.10</td>
<td>0.25</td>
<td>0.17</td>
<td>0.06</td>
</tr>
<tr>
<td>Nature relationships 1) Developer</td>
<td>-0.08</td>
<td>0.35</td>
<td>-0.36</td>
<td>$&lt;0.001$</td>
<td>-0.08</td>
<td>0.35</td>
<td>0.15</td>
<td>0.09</td>
</tr>
<tr>
<td>2) Guardian</td>
<td>0.006</td>
<td>0.94</td>
<td>0.13</td>
<td>0.13</td>
<td>0.08</td>
<td>0.34</td>
<td>-0.01</td>
<td>0.91</td>
</tr>
<tr>
<td>3) Spectator</td>
<td><strong>0.49</strong></td>
<td>$&lt;0.001$</td>
<td><strong>0.25</strong></td>
<td><strong>0.003</strong></td>
<td>-0.03</td>
<td>0.75</td>
<td>0.13</td>
<td>0.13</td>
</tr>
</tbody>
</table>
an Integrated attitude toward science said: “It’s happening in certain areas where you still see some [cottonwood regeneration] but not like you would under the natural system and probably won’t unless you were to remove the dam and restore that hydrograph, and that ain’t gonna happen. […] You have to really think about what your end expectation is, what that desired condition is in relation to its potential now, not historically what it was but its potential now based on all the other influences that are influencing the system” (Manager 110). I also did not have a large sample size for the manager attitude analyses, as the attitude data came from the 18 primary managers who were interviewed; a larger sample size and a more targeted survey to address attitudes, specifically, is needed to test the possible subtle effects of attitude toward science on restoration outcomes. Sites with more desirable conditions (native cottonwood gallery forest) were associated with managers who saw themselves as a small and insignificant part of nature as a whole (“Spectator”; Table 2.3, Figure 2.5a). This is an interesting relationship as the values such as allowing recovery and “nature has final say”, which are associated with Spectator, tend to be aligned with a more hands-off approach; further research is needed with a more targeted assessment of relationship with nature and a larger sample size. It is also possible that the more favorable conditions (in terms of plant community) may foster the Spectator ethic.

Conversely, those managers who were focused on restoring ecosystems for the ultimate benefit of humans (“Developer”) had sites that were less desirable (exotic) and trended toward upland plant communities (Table 2.3, Figure 2.5b). I believe that the Developer ethic of these managers is likely to have been more of a result rather than a cause of the plant community. When projects had more upland plant communities, water-
Figure 2.5: Regressions of plant community composition by attitude: a) degree to which the manager is a spectator (see humans as a smaller and insignificant piece of nature as a whole) and b) the degree to which the manager is a developer (focused on restoring ecosystems for human benefit). Plant community metrics are principal component axes created from all vegetation abundance data (800 observations). Shading indicates confidence interval. Shown are significant ($p<0.05$) Spearman’s rho correlations only.
related goals tended to be a higher priority, making it likely that more channel
maintenance and flow manipulations are being conducted, which in turn requires more
engineering and human intervention, corroborating the recommendation that methods and
management procedures are most effectively dictated by the specific site conditions
(González et al. 2017a). When the plant community is dominated by exotics, managers
may be more motivated to remove them due to potential danger toward humans (“It was
this huge wakeup call that some people were saying we love the bosque, we love the
woods, but it’s a tinder box, it’s really unsafe,” Manager 113) or bad aesthetics (“It’s nice
not to camp in a patch of thistle or tamarisk,” Manager 101). There has also been a
general tendency among managers to have a negative perception of exotic plants,
regardless of their actual impact on ecosystems (Stromberg et al. 2009), and it is possible
that this tendency is stronger for managers who more closely align with Developer.

The “Guardian” relationship – similar to “steward” (sensu HAN scale, de Groot
and de Groot 2009) where managers feel a responsibility to take care of nature – was the
most moderate and the most common of the three relationships, so it is not surprising that
it did not predict plant community as there may not have been enough variability in that
relationship category to distinguish differences in plant community composition.

Limitations of the quantitative data

While the database covered a large area and had comprehensive vegetation data,
not all sites had data from before and after restoration, so there was no way to determine
success in terms of change in a site over time. As mentioned in the previous sections,
further investigation also needs to be taken to determine if the correlated variables are
causal, coincidental, or a proxy for some other variable that was not measured.
Furthermore, it is important to note that many of the tests (especially for management decisions and manager attitudes) were subject to pseudoreplication because when the sample unit was site or project, the responses of managers who had jurisdiction over multiple sites/projects were necessarily replicated. Alternatively, I could have used the mean values for site data by manager, but important variability between sites and projects would have been lost. Pseudoreplication can inflate the significance of results and thus make a Type I error more likely, so conclusions must be made cautiously and warrant further investigation. However, most of the results were highly significant, increasing confidence that these relationships and patterns are meaningful.

Qualitative data analysis

There were more commonalities among the thoughts of the managers with the most desirable plant communities (i.e., characterized by mesic and native species, with a cottonwood overstory) than among the managers with the least desirable plant communities. Managers with desirable sites talked about using science, collaboration, and logistics more than the average of all managers (see Appendix D, Table S2.2 for all frequencies of code groups from interviews).

Managers with desirable sites also stressed learning from past mistakes and maximizing efficiency both in gathering information and treating their sites, that is, adaptive management. Learning and managing, according to one manager, is “just a process of repeated iterations of conversations between people with technical expertise” where the conversations are about “how’s this working and what are we learning from this and how could we tweak it to make it better or more efficient or whatever” (Manager
so not only learning from their own experiences but from others’ as well. In maximizing the efficiency of treatments, it can be a “cost-benefit, I know that in these areas where we do still relatively have some intact native riparian vegetation, if we just go in there and reduce that competition with tamarisk and treat weeds and reduce that, that we’re more than likely not going to have to go in and do any active restoration meaning seeding or planting because we’re just gonna let it hopefully expand over time” (Manager 110).

These managers were also aware of the human-caused changes and hydrological changes that have helped drive the conditions on their sites, and used detailed planning and quantifiable goal assessment. When discussing the importance of planning, one manager said: “I think that mistakes made early on get compounded and very hard to change later in the process. […] Very early in a project you need to get all the ducks in a row, you need a sound monitoring design because you are about to spend 60 or 70, or 80,000 dollars on something and then do you really want to be 7 years down the road looking at the data saying ‘oh, we didn’t collect this correctly, we can’t use it’” (Manager 109). Another manager reiterated this, saying that “the best projects have a pretty well-defined design” (Manager 113). Watershed partnerships in some cases facilitated and standardized the planning process for some managers, because “in order to keep the partnership going and to keep money coming into the partnership from outside donors, from within the government is they need to know what the goals, objectives are. They need to be measureable on how we are going to measure them so that we can tell them where we’re at and there’s an endpoint” (Manager 110).
Managers with less desirable plant communities in their sites had fewer common themes. Overall, these managers talked less about collaboration, public relations and use of science than the average of all managers, and talked more about information, but there was a lot of variability. One of these projects was small and co-managed by a state and federal agency, where the federal agency owned the land and that manager was very focused on the fact that the tracts of land were investments to be protected while the managers from the state agency had to appease the owning agency while protecting wildlife habitat. The second project was municipal with management input from a collaboration, but the project was abandoned for a few years after initial removal (for which I have vegetation data during and immediately after) and only recently has been revived since the new manager (who was interviewed) took the project over. Another project was located in a wetland area, so the vegetation was necessarily different than the truly riparian sites, and the final project with less desirable vegetation was started around 2003 when the vegetation data was collected and was the very first project implemented by the manager who still works there. Thus, many project-specific factors may be the biggest barriers to fostering desirable plant communities in these projects, one of which is the temporal gap between vegetation and survey/interview data collection when linking the two sets of data.

In addition to the manager characteristics and management decisions covered in the surveys, four aspects of restoration projects emerged from all of the interviews as important to achieve successful outcomes: funding, staff, time commitments, and watershed partnerships. Funding was mentioned by all managers. Some talked about utilizing collaborations to get more funding. Others had a more cynical view as they
would secure funding too quickly to use it with proper planning: “it just seems like we’re running at breakneck speeds all the time to chase that money and that you’re not really going ‘ok, well we do have a monitoring protocol, right?’” (Manager 115). In many cases, methods would change depending on the funding: “we had a fairly straightforward monitoring adaptive management plan that [was approved], but then we had all of these other components that weren’t in the plan but they were like ‘if you have the funding, it’s ok to do those things’, but they couldn’t guarantee they would always have the funding” (Manager 114); “often there’s money to get the project done but there’s not really money to monitor or to retreat” (Manager 124); “when you’re starting out you have to pick projects that you’re reasonably certain are going to be successful given the resources that you have because otherwise people aren’t going to want to keep giving you money” (Manager 130).

In addition to being limited by money, many managers with both desirable and undesirable plant communities in their sites talked about the importance of having enough staff to implement their restoration efforts, especially for follow-up treatments and monitoring. Staff cuts made projects more difficult for some managers, particularly for municipalities. One manager with a state agency said “we talked about having a heavy monitoring program but we just never had the bodies” (Manager 116). Some managers contract out to mitigate difficulties related to having a small staff, but not all agencies can afford that. The time commitments of managers also were mentioned frequently. Most of the managers I talked to had many other duties in their positions besides the restoration work, so did not have the time to devote to more comprehensive monitoring or gathering information. Some managers started restoration projects with the
condition that they work full-time on that project, but not all managers were able to do that.

Watershed partnerships came across as important as well. Most of the managers were a part of a watershed partnership, some of which were mandated involvement and some were voluntary. Managers who were a part of the Dolores River Restoration Partnership (DRRP), for example, expanded on the praise given in a case study done by Oppenheimer et al. (2015), where the DRRP was mentioned as an effective model partnership that could be replicated in other regions. Other partnerships were less effective, either because the participants were not invested in the partnership or because the relationships between participants were still being forged. One manager said that for watershed partnerships, “you have to go through a lot of growing pains and you have to get people in the right spot, the right people in the right positions. You need to have that commitment from all the players” (Manager 110). These aspect of projects mentioned by managers warrant more in-depth exploration in future research as they may be associated with plant community.

Conclusion

The traits of land managers and the management decisions they make appear to be strongly connected to the composition of the plant community, as illustrated here by Tamarix removal projects in the Southwest US. Sites with a different managing and owning agency improved the desirability of plant community composition, and this study provides evidence for indirect effects of goals and collaboration on riparian vegetation. According to my interviews, the available resources (such as money, staff, or time) also
influence restoration outcomes, and further research needs to be done in order to investigate what management actions (both direct and indirect) are most strongly affected by availability of resources. My study is the first to corroborate the assumptions of the importance of indirect, general management decisions made by both the scientific and management communities with the ecological outcomes in restoration projects to complement the body of literature on the affects of direct restoration actions. We now also have a better understanding of the additional problems managers face in restoration projects that have previously been overlooked or were considered to be less important, and can more easily target specific obstacles to successful restorations.
REFERENCES


APPENDIX A: Additional Data Collection Materials

The full survey questions are as follows:

1. Which describes your role? Select all that apply:
   a. Directly make land/resource management decisions
   b. Responsible for implementing management decisions made by someone else (e.g., a supervisor)
   c. Oversee restoration projects with input from a team or partnership
   d. Collect data on management actions
   e. Other (specify)

2. How long have you been a land/resource manager?
   a. Less than 2 years
   b. 2-5 years
   c. 6-10 years
   d. 11-20 years
   e. More than 20 years
   f. I am not a land/resource manager.

3. Is the ownership consistent across all land you work with?
   a. Yes
   b. No

4. (If yes) Which best describes your land’s ownership?
   a. Federal (e.g., BLM, USFS, etc.)
   b. State (e.g., State Forest Service)
   c. Non-profit (e.g., land trust)
d. Private

e. Other (specify)

5. (If a selected for question 4) Which federal agency owns the land you manage?
   a. Bureau of Land Management
   b. US Fish and Wildlife Service
   c. National Park Service
   d. US Forest Service
   e. Other (specify)

6. (If b selected for question 4) Which state agency owns the land you manage?
   a. State Fish and Wildlife Service
   b. State Forest Service
   c. State Park Service
   d. Other (specify)

7. Is the managing agency consistent across all land you manage?
   a. Yes
   b. No

8. (If yes) Who makes management decisions on your land? Select all that apply.
   a. Federal agency personnel
   b. State agency personnel
   c. County personnel
   d. Private individuals
   e. Other (specify)
9. How many codes were you given? [minimum of 1, maximum of 8]

_______ codes

10. Enter the first (or only) code here.

11. Please list the location/name of the sites this code refers to.

12. (If no to question 3) Which best describes the ownership of these sites?

   a. Federal (e.g., BLM, USFS, etc.)
   b. State (e.g., State Forest Service)
   c. Non-profit (e.g., land trust)
   d. Private
   e. Other (specify)

13. (If a selected for question 12) Which federal agency owns the land you manage, corresponding to this code?

   a. Bureau of Land Management
   b. US Fish and Wildlife Service
   c. National Park Service
   d. US Forest Service
   e. Other (specify)

14. (If b selected for question 12) Which state agency owns the land you manage, corresponding to this code?

   a. State Fish and Wildlife Service
   b. State Forest Service
   c. State Park Service
   d. Other (specify)
15. (If no to question 7) Who makes management decisions for these sites? Select all that apply.
   a. Federal agency personnel
   b. State agency personnel
   c. County personnel
   d. Private individuals
   e. Other (specify)

16. How long have you been working in this specific area?
   a. Less than 2 years
   b. 2-5 years
   c. 6-10 years
   d. 11-20 years
   e. More than 20 years

17. What were your specific restoration goals for these sites? Select all that apply.
   a. Improve native plant diversity
   b. Aesthetics
   c. Forage supply for livestock
   d. Water access for livestock
   e. Recreational access to water
   f. Ecosystem resilience (i.e., ability to recover from disturbance)
   g. Removal of exotic plants
   h. Wildfire mitigation
   i. Channel maintenance
j. Restore natural flows/over-bank flooding

k. Habitat improvement

l. Water quality

m. Endangered species

n. Other (specify)

18. Please rank your selected restoration goals in importance with 1 as the most important by dragging and dropping them.

19. What was your biggest concern in managing these sites?

*Repeat questions 10-19 for each code*

20. How much do these information sources influence your decisions? (1= Not influential at all, 2= Not very influential, 3= Somewhat influential, 4= Very influential, 5= Extremely influential, Do not use)

a. Bureau of Land Management (BLM)

b. US Forest Service (USFS)

c. US Fish and Wildlife Service (USFWS)

d. State Weed Coordinator

e. County weed coordinator (or other county officials)

f. NRCS

g. Extension service

h. State Forest Service

i. Water Conservation Districts

j. USDA-ARS (Agricultural Research Service)

k. The Nature Conservancy
l. Tamarisk Coalition
m. US Geological Survey (USGS)
n. Personal communication with neighbors/peers
o. Scientific articles
p. Private consultants (e.g., Habitat Management Inc., Rim to Rim Restoration, etc.)
q. Newspaper/magazine articles
r. Supervisor/employer
s. Workshops/Conferences
t. Short-courses
u. Email/listserv communications
v. Personal past experience in the area

21. (For every agency selected 3, 4, or 5 in question 20) List specific resources (if any) from these agencies/information sources that you find particularly helpful.

22. Are there any other information sources that you use?
   a. Yes
   b. No

23. (If yes) Please list any other information sources and where they come from.

24. Is there ongoing monitoring of restoration projects on your land?
   a. Yes
   b. No

25. (If no) Why is monitoring not being done?
26. (If yes to question 24) Who performs/performed the monitoring? Select all that apply.
   a. Yourself
   b. Other personnel in your agency
   c. Collaborators
   d. University scientists
   e. Private consultants
   a. Other (specify)

27. (If yes to question 24) Which monitoring methods do you use? Select all that apply.
   a. Visual (e.g., repeat photographs from a particular point)
   b. Biological (e.g., fish populations or riparian vegetation)
   c. Physical (e.g., channel cross-sections or pebble counts)
   d. Chemical (e.g., dissolved oxygen or water temperature)

28. (If a selected for question 27) How often do you use visual methods?
   a. More than once a year
   b. Once a year
   c. Once every other year
   d. Every 5 years
   e. Less than every 5 years
   f. Other (specify)

29. (If a selected for question 27) In one sentence, how do you visually monitor?
30. (If b selected for question 27) How often do you use biological methods?
   a. More than once a year
   b. Once a year
   c. Once every other year
   d. Every 5 years
   e. Less than every 5 years
   f. Other (specify)

31. (If b selected for question 27) In one sentence, how do you biologically monitor?

32. (If c selected for question 27) How often do you use physical methods?
   a. More than once a year
   b. Once a year
   c. Once every other year
   d. Every 5 years
   e. Less than every 5 years
   f. Other (specify)

33. (If c selected for question 27) In one sentence, how do you physically monitor?

34. (If d selected for question 27) How often do you use chemical methods?
   a. More than once a year
   b. Once a year
   c. Once every other year
   d. Every 5 years
   e. Less than every 5 years
   f. Other (specify)
35. (If d selected for question 27) In one sentence, how do you chemically monitor?

36. Who do you work in partnership with on a regular basis as a land manager? Select all that apply.
   a. Federal agency personnel
   b. State agency personnel
   c. Private consultants
   d. Scientists
   e. Neighbors/Peers
   f. Other (specify)

37. (If d is selected for question 36) Which agency or agencies do the scientists you collaborate with work for? Select all that apply.
   a. Federal
   b. State
   c. County
   d. Private consultants
   e. Non-profit agency
   f. Universities
   g. Other (specify)

38. Who is responsible for research on your land? Select all that apply.
   a. Yourself
   b. University scientists
   c. Other scientists (specify)
39. What is your highest level of formal education?
   a. Less than high school
   b. High School diploma/GED
   c. Some college/technical school
   d. Associate’s degree
   e. Bachelor’s degree
   f. Master’s degree
   g. Doctorate
   h. Prefer not to answer

40. Any additional comments or information you’d like to share?

The following is the template of possible interview questions.

1. Please talk me through any experience with restoration or conservation you had before taking this job.

2. What did you get your degree in?
   a. Do you find that it helps you do your job?

3. You said you have worked as a land manager here for ___ years. What kind of changes have you seen since you started, in terms of the riparian areas?

4. How did this particular project come about?

5. How involved were you?

6. Are you still doing restoration on these sites?
7. What are the positives and negatives of having multiple managing agencies here?
   a. (If not covered in response to the previous question) How does it affect decision making?

8. Tell me about the individual collaborations (give specific examples taken from survey) you are a part of. Do they work? How have they impacted this project?

9. Which of the people involved in this project are scientists?

10. What differences, if any, do you see in working with agency scientists rather than university scientists?

11. What information sources do you use the most?
   a. Why are they the most useful for you?
   b. Ask about USFWS and Tamarisk Coalition if they don’t come up on their own.

12. You said that _____ was not influential at all. Why not?

13. Are there kinds of information or other sources you wish you had access to?

14. Why is removal of exotic plants not one of your selected goals?

15. How were the overall goals for this project generated?
   a. If not addressed: were there differences among the multiple agencies involved in managing the site?
   b. If so, how were those differences reconciled?

16. How do you determine if these goals have been met?

17. Who decides what monitoring methods you use?

18. What do you do with the data?

19. Do you consider this project to be successful? Why/why not?
20. Is there anything else I didn’t ask about that you think I should know?

21. Is there anyone you recommend I interview?
## APPENDIX B: Possible Options For Tallied Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Possible options</th>
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</thead>
<tbody>
<tr>
<td>Management roles</td>
<td>Directly make management decisions</td>
</tr>
<tr>
<td></td>
<td>Implement management decisions made by others</td>
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<tr>
<td></td>
<td>Oversee project with input from a partnership</td>
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<tr>
<td></td>
<td>Collect data</td>
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<td></td>
<td>Other</td>
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<tr>
<td>General collaboration</td>
<td>Federal</td>
</tr>
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<td>State</td>
</tr>
<tr>
<td></td>
<td>Private consultants</td>
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<tr>
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<td>Scientists</td>
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<td>Neighbors/peers</td>
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<td></td>
<td>Other</td>
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<td>County</td>
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<td>Private consultants</td>
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<tr>
<td></td>
<td>Non-profit agency</td>
</tr>
<tr>
<td></td>
<td>Universities</td>
</tr>
<tr>
<td></td>
<td>Other</td>
</tr>
<tr>
<td>Research collaboration</td>
<td>Self</td>
</tr>
<tr>
<td></td>
<td>University scientists</td>
</tr>
<tr>
<td></td>
<td>Other scientists</td>
</tr>
<tr>
<td>Information sources</td>
<td>see Appendix A, question 20</td>
</tr>
<tr>
<td>Monitoring methods</td>
<td>Visual (e.g., repeat photography)</td>
</tr>
<tr>
<td></td>
<td>Biological (e.g., fish or vegetation inventory)</td>
</tr>
<tr>
<td></td>
<td>Physical (e.g., channel cross-section)</td>
</tr>
<tr>
<td></td>
<td>Chemical (e.g., dissolved oxygen)</td>
</tr>
</tbody>
</table>
APPENDIX C: Attitude Assessment Criteria

Figure S1.1: There were two distinct attitudes toward science (a): a Polarized attitude (left) where managers see themselves as very different and separate from researchers and use very little or no scientific knowledge or skills, and an Integrated attitude (right) where there is no distinction between practitioners and researchers and scientific practices, skills, and knowledge are used on a regular basis. There were three relationships with nature (b): Developer (left) where humans are separate from nature and technology is used to develop nature for human benefit, Guardian (middle) where humans are equal to nature and take care of it so that nature is there for future generations, and Spectator (right) where humans are a small part of nature as a whole and nature will take its course regardless of human actions.
<table>
<thead>
<tr>
<th>Attitude</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science: Polarized</td>
<td>academia glorified, academic more flexible than applied, agency bias,</td>
</tr>
<tr>
<td></td>
<td>limited science, need science liaison, not consistent, polarized science,</td>
</tr>
<tr>
<td></td>
<td>restore to historical, science cynicism, subjective goals</td>
</tr>
<tr>
<td>Science: Integrated</td>
<td>academic and applied similar, complement each other, good science</td>
</tr>
<tr>
<td></td>
<td>liaison, integrated science, quantifiable goal assessment, question-driven, rely on academics, same science goals, science for validation, scientific skills, utilize data</td>
</tr>
<tr>
<td>Nature: Developer</td>
<td>business first, control, create water/wetland, development, engineer</td>
</tr>
<tr>
<td></td>
<td>ecosystem, investment, mandated, protect mandated wildlife, threat to</td>
</tr>
<tr>
<td></td>
<td>humans, valuable plants</td>
</tr>
<tr>
<td>Nature: Guardian</td>
<td>bad plants, crucial intervention, detrimental changes, good human-caused changes, healthy river, mitigation/reclamation, protect all wildlife, protect nature, restore wetland habitat, right trajectory, stewardship, utilize nature</td>
</tr>
<tr>
<td>Nature: Spectator</td>
<td>allow recovery, learn from the river, luck, nature fights back, nature</td>
</tr>
<tr>
<td></td>
<td>has final say, nature is a remarkable force, river vs. policy,</td>
</tr>
<tr>
<td></td>
<td>unpredictable</td>
</tr>
<tr>
<td>Weight</td>
<td>Reason</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>All</td>
<td>quote also associated with &quot;passion&quot; code</td>
</tr>
<tr>
<td>x 2</td>
<td>repeatedly mentioned or elaborated as an answer to the same question related to agency, rather than personal opinion talking about someone else's actions/views</td>
</tr>
<tr>
<td>x 0.5</td>
<td>hopeless to regain function without humans</td>
</tr>
<tr>
<td>Developer</td>
<td>strong language</td>
</tr>
<tr>
<td>x 2</td>
<td>not aligned with developer, but related</td>
</tr>
<tr>
<td>x 0.5</td>
<td>project itself is a threat to humans</td>
</tr>
<tr>
<td></td>
<td>cynical wording</td>
</tr>
<tr>
<td>Guardian</td>
<td>strong language</td>
</tr>
<tr>
<td></td>
<td>passionate inflection took strong action</td>
</tr>
<tr>
<td>x 0.5</td>
<td>not aligned with guardian, but related</td>
</tr>
<tr>
<td>Spectator</td>
<td>passionate inflection cynical about human intervention</td>
</tr>
<tr>
<td>Weight</td>
<td>Reason</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Spectator continued</td>
<td>x 0.5</td>
</tr>
<tr>
<td>Integrated</td>
<td>x 2</td>
</tr>
<tr>
<td>x 0.5</td>
<td>not aligned with integrated, but related unrealistic expectation</td>
</tr>
<tr>
<td>Polarized</td>
<td>x 2</td>
</tr>
<tr>
<td>x 0.5</td>
<td>talking about how to improve limited by a factor out of their control</td>
</tr>
<tr>
<td>not aligned with polarized, but related</td>
<td>&quot;I'm not necessarily wedded to the idea that you have to be able to show [success] statistically&quot;</td>
</tr>
</tbody>
</table>

*When one quote is associated with multiple codes of the same category, only counted once.
## APPENDIX D: Interview Codes and Themes

Table S2.1: Full list of interview codes and associated themes.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Integrated science</strong></td>
<td>academic and applied similar, complement each other, good science liaison, integrated science, quantifiable goal assessment, question-driven, rely on academics, same science goals, science for validation, scientific skills, utilize data</td>
</tr>
<tr>
<td><strong>Polarized science</strong></td>
<td>academia glorified, academic more flexible than applied, agency bias, limited science, need science liaison, not consistent, polarized science, restore to historical, science cynicism, subjective goals</td>
</tr>
<tr>
<td><strong>Developer</strong></td>
<td>business first, control, create water/wetland, development, engineer ecosystem, investment, mandated, protect mandated wildlife, threat to humans, valuable plants</td>
</tr>
<tr>
<td><strong>Guardian</strong></td>
<td>bad plants, crucial intervention, detrimental changes, good human-caused changes, healthy river, mitigation/reclamation, protect all wildlife, protect nature, restore wetland habitat, right trajectory, stewardship, utilize nature</td>
</tr>
<tr>
<td><strong>Spectator</strong></td>
<td>allow recovery, learn from the river, luck, nature fights back, nature has final say, nature is a remarkable force, river vs. policy, unpredictable</td>
</tr>
<tr>
<td><strong>Administrative</strong></td>
<td>agency obligations, detailed planning, endangered species driven, eyes bigger than stomach, fire driven, funding cynicism, funding driven, good building blocks, intensive management, lack of planning, limited resources, localized planning, maximize treatment efficiency, mitigation-driven, no support, passion, policy, reactionary management, staff support, staff turnover challenges, success agreement, success difference, wetland</td>
</tr>
<tr>
<td><strong>Beetles</strong></td>
<td>against beetles, beetle conflict with SWFL, beetle fire danger, beetle impacts, beetle unknowns, beetles fill in gaps, for beetles</td>
</tr>
<tr>
<td><strong>Collaboration</strong></td>
<td>advocate for own project, agency isolation, bureaucracy, collaboration dictates scale, collaboration for funding, collaboration forces involvement, cultural challenges, DRRP model, extensive discussion, fragile egos, interpersonal challenges, minimal collaboration, partnership excitement, partnership frustration, private challenges, robust with collaboration, specialized partnership roles, trust</td>
</tr>
</tbody>
</table>
Table S2.2: Frequency of occurrence of themes in interviews. Percentages based on total number of codes for each column.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Codes</th>
<th>Least desirable (n=6)</th>
<th>Moderately desirable (n=11)</th>
<th>Most desirable (n=6)</th>
<th>All managers (n=23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecosystem</td>
<td>changed ecosystem, changed hydrology, fire impact, landscape scale, local conditions, long-term, persistence, short term</td>
<td>23%</td>
<td>24%</td>
<td>28%</td>
<td>20%</td>
</tr>
<tr>
<td>Information</td>
<td>advocate for own CE, fire experience, individual interactions, information &gt; source, information access, know who to talk to, lack of knowledge, lessons learned, local knowledge, local resources, maximize gathering efficiency, no experience, restoration experience</td>
<td>3%</td>
<td>3%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Public relations</td>
<td>aesthetic perception gap, community connection, good public awareness, historical impacts, need to improve public awareness, paradigm shift, public conflict, recreation conflict, recreation-driven, remote</td>
<td>10%</td>
<td>18%</td>
<td>16%</td>
<td>13%</td>
</tr>
<tr>
<td>Use of science</td>
<td>comprehensive goals, critical thinking, funding impacts monitoring, integrated science, limited science, monitoring challenges, monitoring impacts funding, not consistent, old methods, quantifiable goal assessment, question-driven, realistic goals, restore to historical, same science goals, scientific skills, selective monitoring, subjective goals, utilize data</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
<td>6%</td>
</tr>
</tbody>
</table>

*Non-weighted proportions
Figure S1.2: Mean (+/- SE) priority of people-related goals by managing agency. Different letters indicate significantly different means (Mann-Whitney, Bonferroni adjusted α: p<0.005).
Figure S1.3: Regression of prioritization of plant- or wildlife-related goals by proportion of sites with heavy machinery removal (left) and burning (right). Shading indicates confidence interval. Showing significant (adjusted alpha: \( p < 0.01 \)) and marginally significant correlations only.
Table S1.3: Differences between cluster groups for management roles, experience, education, agency, information sources, monitoring, and collaboration. Clusters were created using all manager variables (characteristics and decisions; PAM method using Gower distances, AWS=0.13). Shown are the percentages of all managers in each group who selected each management role, the median value of each group for the continuous variables with the range in parentheses, or the most commonly selected category of each group for the categorical variables. Coefficients are either Pearson’s chi-square (categorical variables) or Mann-Whitney U (continuous variables). Significant results are in bold ($p<0.05$).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group 1</th>
<th>Group 2</th>
<th>coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct management role$^{+}$</td>
<td>69%</td>
<td>67%</td>
<td>0.02</td>
<td>0.89</td>
</tr>
<tr>
<td>Implement decisions made by others$^{+}$</td>
<td>28%</td>
<td>20%</td>
<td>0.36</td>
<td>0.55</td>
</tr>
<tr>
<td>Oversee projects with input from a partnership$^{+}$</td>
<td>63%</td>
<td>73%</td>
<td>0.53</td>
<td>0.47</td>
</tr>
<tr>
<td>Collect data$^{+}$</td>
<td>38%</td>
<td>40%</td>
<td>0.03</td>
<td>0.87</td>
</tr>
<tr>
<td>Median breadth of management roles (0-4)$^{+}$</td>
<td>1</td>
<td>2</td>
<td>0.25</td>
<td>0.61</td>
</tr>
<tr>
<td>Most common experience level</td>
<td>11-20 years</td>
<td>11-20 years</td>
<td>0.83</td>
<td>0.84</td>
</tr>
<tr>
<td>Most common education level</td>
<td>Bachelors</td>
<td>Masters</td>
<td>7.41</td>
<td>0.06</td>
</tr>
<tr>
<td>Most common employing agency</td>
<td>Federal</td>
<td>Local</td>
<td><strong>22.82</strong></td>
<td><strong>&lt;0.001</strong></td>
</tr>
<tr>
<td>Most common type of information sources</td>
<td>mix</td>
<td>mix</td>
<td>3.28</td>
<td>0.19</td>
</tr>
<tr>
<td>Median breadth of information sources (0-22)</td>
<td>18</td>
<td>19</td>
<td>0.03</td>
<td>0.87</td>
</tr>
<tr>
<td>Median breadth of monitoring methods (0-4)</td>
<td>2</td>
<td>2</td>
<td><strong>6.90</strong></td>
<td><strong>0.009</strong></td>
</tr>
<tr>
<td>Most common monitoring frequency</td>
<td>every 1-2 years</td>
<td>every 1-2 years</td>
<td>1.12</td>
<td>0.77</td>
</tr>
<tr>
<td>Median breadth of monitoring groups (0-6)</td>
<td>2</td>
<td>2</td>
<td><strong>9.11</strong></td>
<td><strong>0.003</strong></td>
</tr>
<tr>
<td>Median breadth of collaborating groups (0-7)</td>
<td>2</td>
<td>4.5</td>
<td><strong>7.38</strong></td>
<td><strong>0.007</strong></td>
</tr>
<tr>
<td>Median breadth of science collaborators (1-7)</td>
<td>3</td>
<td>5</td>
<td>3.39</td>
<td>0.07</td>
</tr>
<tr>
<td>Median breadth of researching groups (0-4)</td>
<td>2</td>
<td>1</td>
<td>3.71</td>
<td>0.05</td>
</tr>
</tbody>
</table>

$^{+}$ 1.7% weight; other variables have 8.3% weight
Figure S1.4: Histogram representing frequency of managers within each manager cluster group by normal precipitation (average over 30 years, mm, dark bars) and normal maximum temperature (average over 30 years, degrees C, light bars). Managers in group M1 (top) were mostly federal, insular, and did less monitoring, while group M2 (bottom) were from other agencies, and collaborated and monitored more (see Table 2). Showing significant ($p<0.05$) relationships only.
Figure S1.5: Manager-designated highest priority goal group based on local conditions: a) mean (+/− SE) normal precipitation (mm), b) mean (+/− SE) maximum normal temperature (°C), and c) mean (+/− SE) minimum normal temperature (°C). Water-related goal as highest priority excluded (n=1). Showing significant relationships (adjusted alpha: p<0.004) and trends only.
Figure S2.1: Mean (+/- SE) site score of plant community composition by manager cluster group; managers in group M1 (n=173 sites) are mostly federal and collaborate with less groups and monitor less than managers in group M2 (n=54 sites; PAM clusters using Gower distance; see Table 1 for detailed group descriptors). Plant community metrics “overstory” and “xeric” are Principal Component axes created from all vegetation abundance data (800 observations). Sample sizes are the number of sites in each group. Only trends are shown from mixed models with manager as random effect (Bonferroni adjusted α: p<0.013).

Figure S2.2: Combinations of owning and managing agencies for the same site.
Figure S2.3: Mean (+/- SE) site scores of plant community composition based on managing agency (private/local, n=20 sites; state, n=17 sites; federal, n=128 sites; collaborative, n=62 sites). Plant community metrics are Principal Component axes created from all vegetation abundance data (800 observations). Different letters indicate significantly different means (mixed model with project as random effect, Bonferroni adjusted $\alpha$). Shown are marginally significant relationships only (Bonferroni adjusted $\alpha$: $p<0.013$).
Figure S2.4: Mean (+/- SE) site score of plant community composition by a) employing agency and b) owning agency (private, n=22 sites; local, n=28 sites; state, n=6 sites; federal, n=163 sites; collaborative, n=8 sites). Plant community metrics are Principal Component axes created from all vegetation abundance data (800 observations). Different letters indicate significantly different means (mixed model with manager as random effect, Bonferroni adjusted α). Sample sizes are the number of sites in each category. Shown are significant relationships (Bonferroni adjusted α: p<0.013) or trends only.
Figure S2.5: Plant community structure in a regression (shading indicates confidence interval) with breadth of management roles. Plant community metrics are principal component axes created from all vegetation abundance data (800 observations). Shown are significant relationships only (Bonferroni adjusted $\alpha$: $p<0.013$).
Figure S2.6: Regression of plant community composition by the number of information sources used by managers. Plant community metrics are principal component axes created from all vegetation abundance data (800 observations). Shading indicates confidence interval. Shown are significant (Bonferroni adjusted $\alpha$: $p<0.013$) Spearman’s rho correlations only.