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Citizen Science Ecological Monitoring: For Whom?

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BY

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B.A. PHILOSOPHY & GERMAN STUDIES
TEXAS A&M UNIVERSITY
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THESIS

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DEDICATION

In memory of Papa John A. Fambrough. From the dog-eared pages of your copy of the classic, I found perfect inspiration. We miss you.

"To me an ancient cottonwood is the greatest of trees because in his youth he shaded the buffalo and wore a halo of pigeons, and I like a young cottonwood because he may some day become ancient."

"The evolution of a land ethic is an intellectual as well as emotional process. Conservation is paved with good intentions which prove to be futile, or even dangerous, because they are devoid of critical understanding either of the land, or of economical land-use. I think it is a truism that as the ethical frontier advances from the individual to the community, its intellectual content increases. The mechanism of operation is the same for any ethic: social approbation for right actions: social disapproval for wrong actions. By and large, our present problem is one of attitudes and implements. We are remodeling the Alhambra with a steam-shovel, and we are proud of our yardage. We shall hardly relinquish the shovel, which after all has many good points, but we are in need of gentler and more objective criteria for its successful use."

-*Aldo Leopold,* A Sand County Almanac

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ABSTRACT

In ecosystems undergoing rapid change, habitat management and restoration present special challenges for land managers. To reduce uncertainty about such systems and, thereby, improve the success of their decisions, managers may consult ecological monitoring data. Limitations in time and resources for data collection have highlighted the role that citizen science can play in applied conservation science. One citizen science project, the Bosque Ecosystem Monitoring Program (or BEMP), supplies decision makers with ecological monitoring information about the historically dynamic Middle Rio Grande riparian forest corridor (or *bosque*) ecosystem through engaging nearby K-12 students in collecting ecological data over a large area. However, decision makers' access to this ecological monitoring information does not ensure its use; bosque land managers are not using the available citizen science ecological monitoring information to the extent they could to inform their decisions.

This project's purpose is to reveal what prevents Middle Rio Grande bosque management from benefiting more from ecological monitoring data in general, and citizen science data in particular, when making habitat management and restoration decisions, while also determining what conditions would facilitate decisions informed by ecological monitoring data in this context. Findings from interviews conducted with 18 individuals from 17 entities concerned with the bosque in the Middle Rio Grande constitute the main body of the research, supplemented by a review of relevant literature and documents. Barriers to the application of citizen science monitoring data in the Middle Rio Grande bosque have to do with the decision-making context and whether monitoring data is simultaneously available and useful for management objectives; that the monitoring data derives from a citizen science project is not a barrier to its use. The identified barriers include the lack of time or staff; priorities driven by funding; lack of requirement to make evidence-based decisions; lack of immediately useful information; and the uncertainty of leadership priorities. Interviewees from entities that use decision-making protocols said these support their use of monitoring data for decisions. BEMP generates the only available long-term ecological monitoring data record for the Middle Rio Grande, and the majority of interviewees have used BEMP data for decisions. However, because BEMP's study design necessitates retroactive pattern discovery and because BEMP data analyses are sometimes unavailable and/or do not address management questions, interviewees said that data from the BEMP program is not as useful as it could be for informing bosque management and habitat conservation and reducing uncertainty. Having identified what limits the use of monitoring data for improving bosque management, I

offer recommendations directed to BEMP and bosque management decision makers. These recommendations aim to strategically increase the use of ecological monitoring data to inform management decisions about the Middle Rio Grande bosque.

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1. INTRODUCTION

The sustainable management of ecosystems that are undergoing dramatic change constitutes a major challenge for biological conservation. Current pressures of human land use and climate change amplify the difficulty of habitat management in such ecosystems. In the last few decades, the recognition that ecosystem dynamics can be complex, nonlinear, and often unpredictable has altered land management discussions (Howell et al., 2009). Traditional approaches to natural resource management that are reliant on maintaining non-dynamic equilibrium and stationary states in ecosystems are not useful for resolving instances of structural uncertainty (Holling, 1986; Moore and McCarthy, 2010).

Monitoring biodiversity in space and time is fundamental to understanding ecosystems and their components for conservation (Yoccoz et al., 2001). Natural resource managers are challenged to produce effective conservation outcomes with steadily shrinking resources. At the same time, the management context is increasingly complicated in terms of understanding ecological change and working in the changing institutional and regulatory landscape. To make sustainable management decisions, a manager needs to understand the complex ecological system, as well as the institutional realities.

Ecosystems are shaped by a set of environmental conditions that are difficult to observe because they occur at multiple scales and change. Anthropogenic and other stressors inform these environmental conditions. It can be difficult to reveal which drivers of ecological decline are local and susceptible to impact-mitigation efforts (Nicholson and Possingham, 2007) when, for example, a species' decline is

perhaps more tightly driven by atmospheric temperature than by a local pest outbreak (Williams et al., 2012). Establishing cause and effect relationships in managed, complex ecosystems can be aided by well-designed long-term ecological monitoring studies (see Gitzen et al., 2012). The definition of 'monitoring' is perhaps still subject to debate; for the purposes of this thesis, I look to the definition given by Johnson (2012) who defines monitoring as "repeated measurements collected at a specified frequency of time units" for a duration generally longer than what is needed to collect baseline information or evaluate projects for either implementation or effectiveness (Johnson, 2012). Many in the discussion about the use of ecological monitoring data choose to include the term 'long-term' in connection with monitoring and research to distinguish these from such shorter-term targeted data collection (e.g. Kendall and Moore, 2012; Hutto and Belote, 2013). That monitoring is a longer-term, iterative activity rather than a collection repeated a few times is particularly true for adaptive management because it involves a continuous process of learning.

This paper is organized in six sections. The next section provides background information relevant to this topic by way of a review of academic literature. The third section outlines the setting for this study. The fourth section lays out the method of study, and the fifth section presents the results. The last section is devoted to discussion of the results, recommendations, and conclusions.

2. BACKGROUND

2.1. Complex systems thinking informs adaptive management

Complex systems thinking is premised on the recognition that systems behave as wholes, with emergent properties like self-organization and nonlinearity. Complex systems thinking is useful where system behavior cannot be explained in terms that simply aggregate the individual elements. Since Ludwig von Bertalanffy's early lectures at the University of Chicago (1937-38), general systems thinking has emphasized connectedness, context, and feedback. It suggests that unsuspected connections and surprising shifts should be expected with some regularity. The history of environmental management projects provides endless opportunity to discuss unanticipated, often negative, social and ecological impacts. Using complex systems thinking to address complex problems can help navigate ecosystem management in the current age.

Complex systems thinking has been applied to ecosystem management largely through adaptive management, a framework for structured decision-making that aims to combine the need for immediate action with a plan for learning (Gunderson and Holling, 2002). Adaptive management is closely related to the theoretical framework of ecosystem management (Agee and Johnson, 1988; Szaro et al., 1998) and has been called the "methodological sibling of ecosystem management" (Ruhl, 2008). Adaptive management is applicable when the decision is iterated over time or space and there are competing hypotheses about how the system works. This development reflects the deeper recognition in natural resource management that science does not produce 'conclusions' about environmental systems that are suitable as the basis of lasting policies and regulations about natural resource use. It also recognizes that the outcomes of management actions

are not fully understood or predictable. Instead, as a proactive management approach, it provides guidance for using investigation to improve management outcomes over time in a goal-oriented and structured process (Allen and Holling, 2010).

In 2007, all bureaus within the Department of the Interior were directed to adopt an adaptive management approach whenever possible (Secretary of the Interior Secretariat Order 3270, 2007). In that same year a directive followed from Forest Service Chief Abigail Kimbell to put in place a national environmental management system on all administrative units that provides a disciplined framework for practicing adaptive management (USDA Forest Service FSM1331, 2008). As the National Research Council definition of adaptive management points out, it "does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social and economic goals, increases scientific knowledge, and reduces tension among stakeholders" (Williams et al., 2009: 9).

Adaptive management is an iterative process based on the philosophy that knowledge is incomplete and should be rigorously tested before guiding decisions. The process typically follows a logical, ordered series (Keith et al., 2011; Williams et al., 2009):

1. Clear articulation of management goals.
2. Specification of multiple management options, one of which can be 'do nothing'.

3. Creation of a process for interpreting how the system responds to management interventions, typically including quantitative conceptual models and/or experimental design.
4. Implementation of management action(s).
5. Monitoring the system response to management interventions.
6. Adjust management practice based on results from monitoring and review management goals.

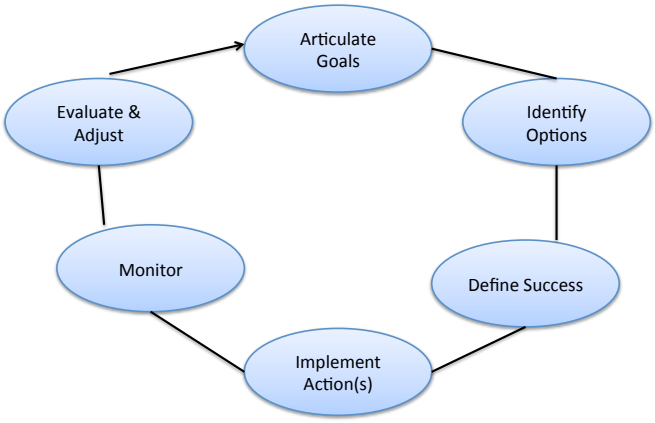

Figure 1: The Adaptive Management Cycle.

It has become popular to lament the challenges and failures of implementing adaptive management (Gregory et al., 2006; Allen and Gunderson, 2011). The challenges to implementing adaptive management, as modified from Allen et al. (2011), include: 1) a lack of clarity in definition and approach (Allen et al., 2011), 2) a paucity of success stories on which to build (Lee, 1999; Walters, 2007), 3) management, policy, and funding paradigms that favor reactive rather than proactive approaches to natural resource management (Walters and Green 1997;

Schreiber et al., 2004), 4) failure to acknowledge the sources of uncertainty that are social rather than ecological, and hence increased risk of surprise (Tyre and Michaels, 2011). Misrepresentations and misunderstandings of adaptive management are plentiful (Allan and Curtis, 2005). But out of the constant assessment of what makes adaptive management so simultaneously impossible and necessary have come some key insights. Walters (2007) asserts that for adaptive management to progress successfully, appropriate financial and human resources need to be made available; institutions should ensure that resources are in place before embarking on adaptive management. Adaptive management is appropriate where both uncertainty and controllability are high, and is less effective for problems of intricate complexity, high external influences, long time spans, high structural uncertainty, and with low confidence in assessments (e.g. climate change, Gregory et al., 2006). Even in such instances, however, adaptive management can help to reduce or resolve structural uncertainty (Allen and Gunderson, 2011). Stakeholder engagement is critical to adaptive management because the ability to conduct adaptive management experiments is largely determined by the degree of collaboration (Walters and Green, 1997; Allen and Gunderson, 2011).

Adaptive management does not promise to reduce uncertainty until there is none; instead it provides a framework for working within the inherent uncertainty in the dynamics and behavior of complex ecological systems.

2.2. Ecological monitoring programs and their challenges

In the past, ecological monitoring was primarily for surveillance and compliance, error detection, or impact assessment reasons. These traditional roles

for monitoring are likely to persist where structures require them, but they are not necessarily related to sustainable ecosystem management. Monitoring in an adaptive management framework shifts the emphasis to gauging how effective decision-makers are at learning. Whether a land management entity has adopted adaptive management as a policy or not, their evidence-based environmental decisions related to conservation will be reliant on monitoring information (Lindenmayer and Likens, 2010).

Unfortunately, long-term studies are notoriously difficult to establish and maintain (Noon 2003, Nichols and Williams 2006, Lindenmayer and Likens, 2010b, Gitzen and Millspaugh, 2012: 3). The challenges to establishing such a program are many, but include knowing whether to monitor at all (McDonald-Madden et al., 2010) securing long-term funding opportunities (Marsh and Trenham, 2008; Caughlan and Oakley, 2001), determining proper study design and purpose (Nichols and Williams, 2006), and the ongoing criticism of existing monitoring programs (Legg and Nagy, 2006; Lindenmayer and Likens, 2009). Once established, long-term monitoring programs face maintenance challenges such as poor data management (Caughlan and Oakley, 2001), loss of integrity of the long-term data record (Strayer et al., 1986), lack and/or loss of funding (Caughlan and Oakley, 2001), and loss of key personnel (Kendeigh, 1982).

In the larger natural resource management discussion, there is no disagreement about the need for long-term monitoring and research (Strayer et al., 1986; Spellerberg, 2005). However, there is debate about one aspect of monitoring that is relevant to this thesis. Some have drawn a distinction between monitoring

that is designed either to test a specific hypothesis or to inform a specific management program, and monitoring that is not in this debate. The later form of monitoring is often referred to as "passive" (Lindenmayer and Likens, 2010) or "surveillance monitoring" (Nichols and Williams, 2006). The three characteristics for "targeted" or "active" monitoring are: well-developed and readily-tractable scientific questions, a conceptual model of the ecosystem(s) in question, and a robust and statistically-based experimental design (Lindenmayer and Likens, 2010). Lindenmayer and Likens (2009; 2010) have taken this position; they set the bar for monitoring programs according to the use and usefulness of the data.[1] Considered generally, surveillance monitoring is able to detect change and is valuable in that capacity to detect a troubling trend indicative of ecosystem degradation.[2] This admittedly long path is the basis for Nichols and Williams' (2006) general criticism: one must first use monitoring results to retrospectively detect changes in

[1] Hutto and Belote (2012) used the above debate as the basis of their recommendation to distinguish four fundamentally different types of monitoring based on the questions the program addresses, which they propose to be used as standards when describing monitoring programs, especially within adaptive management. These four types are surveillance, implementation, effectiveness, and ecological effects. I find these types useful for this discussion because it reveals the multiple roles that monitoring is expected to play in adaptive management. Monitoring should not only inform ecological condition decisions, but also provide a record that can be used for program accountability. Hutto and Belote (2012) offer the four types of monitoring not as a menu, but as each fitting into the adaptive management loop at different phases.

[2] A helpful analogy is that of a nurse routinely monitoring a person's blood pressure and body temperature. The nurse uses abnormal values in these indicators to trigger the need to test for a specific disease, and abnormal values might be the only sign that the person is ill. But this example also highlights a key shortcoming of surveillance monitoring: it is not efficient.tr disease, and abnormal values might be the only sign that the person is ill. But this example also highlights a key shortcoming of surveillance monitoring: it is not efficient.

populations of some species, then either take remedial action or conduct more focused research to identify causes of the changes (Johnson, 2012).

Proponents of monitoring programs that would be called "surveillance" types argue that if these programs are less effective than they could be, this is due to lack of cooperation across scales and disciplines. Rather than a problem of study design, they say the unmet potential has to do with the lack of integration between small-scale stand-alone research studies and long-term ecological research programs (Haughland et al., 2009).

2.3. Role of citizen science monitoring programs

Citizen science has potential to help address some of the challenges of ecological monitoring. Citizen science involves collaboration between scientists and citizen volunteers, and it has become increasingly important in conservation science as resources for monitoring fail to match the questions at hand (Miller-Rushing et al., 2012; Tulloch et al., 2013). Citizen science creates opportunities for ecological research at unprecedented spatial and temporal scales through data collection by a large, dispersed set of observers over relatively long periods of time (Dickinson and Bonney, 2012; Bonney et al., 2009b).

Citizen science spans an enormous range of purposes. For example, researchers in France used breeding bird survey data to reveal that bird communities are shifting northwards, but at a slower rate than temperatures (Jiguet et al., 2011), tourist scuba divers helped researchers to describe the status of biodiversity of the Egyptian coral reef (Branchini et al., 2015), and Swedish hunters' observations have been the basis of Swedish moose management since 2000 (Singh

et al., 2014). In the US, the Cornell Lab of Ornithology is the main hub for citizen science, directing ten projects that collectively gather tens of millions of bird observations each year. The lab's projects are designed to answer scientific questions while helping the public learn about birds and the process of science (Bonney et al., 2009b; *www.cornellcitizenscience.org).*

Citizen science program objectives vary from helping scientists answer questions to offering opportunities for the public to enjoy nature to informing local decisions and engaging in social networks (Bonney et al., 2009b). Citizen science generates monitoring data simply by repeating data collection over time; program objectives determine the data collection protocols and inform how the data are initially analyzed. If program objectives include obtaining data and information needed for managing and understanding ecological systems, a few characteristics of citizen science data will be relevant for the design of studies and analysis of the resultant data. Compared with ecological monitoring studies conducted by science professionals, citizen science data are likely to require 1) greater attention to maintaining consistency in data-collection protocols and potential sources of spatial and temporal bias, 2) data-collection protocols that are not as demanding of data collectors, and 3) additional steps in analyses to investigate the potential that biases exist since data are likely to be re-used for multiple purposes (Hochachka et al., 2012). Because citizen science data are more likely to be usable for multiple and initially unanticipated purposes and because there is usually a low level of control over the study design, Hochachka et al. (2012) recommend methods for exploratory data analysis to discover patterns in citizen science data. Compared with other

ecological surveys, a greater burden falls to the analysis phase of citizen science to be able to produce accurate inferences.[3] Through adjustments to data-collection protocols and methods of analysis, well-designed citizen science-monitoring programs can be useful in addressing management questions, but researchers suggest that more experience of this is needed (Hochachka et al., 2012; Possingham et al., 2012). In contrast to the general trend toward revealing the unanticipated and surprising uses of citizen science data, natural resource mangers need citizen science partnerships that help them to decide which management action to implement where the choice of action depends on the state of the ecosystem, as any ecological monitoring should provide (Possingham et al., 2012; Turner and Richter, 2011).

McKinley et al. (2012) suggest citizen science and participatory monitoring as mechanisms that could enhance the use of science in some natural resource management discussions, possibly leading to supportable solutions. Research into citizen science as a phenomenon has focused on the characteristics of effective, rigorous programs (e.g. Bonney et al., 2009); social trust in the results of citizen science (e.g. Thornton and Leahy, 2012); data management needs (e.g. Newman et al. 2011); and how programs best engage local people (e.g. Constantino et al., 2012; Danielsen et al., 2005a). Citizen science has undoubtedly been successful in contributing to scientific understanding and increasing the public's scientific literacy. The qualities of effective ecological monitoring programs are rigorously

[3] Hochachka et al. (2012) discuss the potential for nonparametric and semi-parametric regression techniques to efficiently discover new relationships in less well-understood systems, and cross-validation as an under-used tool for validation of models resulting from exploratory analysis.

debated and under review. Adaptive management introduces a decision-making framework for reducing uncertainty and learning about managed ecosystems, and research into these claims are many (Allen et al. 2010). The standing question that this study takes on is: Can citizen science monitoring be useful for transferring to natural resource managers and policymakers scientific knowledge that results in learning?

2.4. Environmental governance and uncertainty

While adaptive management works to promote learning, it is the integration of scientific knowledge that poses perhaps the greatest barrier to science-based decisions. Pouyat (1999) and Hayward (2006) have noted that scientists and policymakers have different rules regarding uncertainty, limiting the communication and shared understandings needed for translating science into management. Asher, Steelman, and Healy (2010) describe the consequences of "knowledge problems" in the environmental policy process, and the use of particular decision routines. They argue that the appropriateness of particular routines and of the inputs (i.e. methods and information) must be determined according to relevant scientific standards, which are often subject to scientific dispute (Asher et al., 2010:14). Decision routines will be geared toward the available knowledge, whether these routines are the most appropriate for the common good or not (Asher et al., 2010: 21). Relevant to a study of citizen science, Asher et al. (2010) suggest that a paradigm, the so-called deficit model of citizen involvement, perpetuates certain environmental knowledge problems. This model presumes that the lay public lacks understanding of an issue, but that this

information deficit can be rectified. The model assumes that underlying any management issue is sound and knowable science that, once uncovered will lead to agreement among scientists and, with enough communication, the lay public. The deficit model assumes that scientific knowledge is superior to other forms of knowledge, and that communication should flow from the scientists to the lay public. Scientists, especially ecologists, must accept a level of inherent uncertainty in natural systems. When the deficit model of citizen involvement dominates a decision-making context, it suggests that uncertainty can and should be eventually resolved by professional scientists and "handed down" to the lay public. Citizen science helps to rework such dynamics because the public becomes the source of new knowledge and, because of on-going environmental change and curiosity, it often continues indefinitely.

Institutions are central to governing responses to environmental change. Young (1999) defined institutions as "systems of rules, decision-making procedures, and programs that give rise to social practices, assign roles to participants in these practices, and guide interactions among the occupants of the relevant roles. Young (1999) concludes that the success of environmental institutions depends on their degree of fit with the major features of the biogeophysical systems they are related to. Scientific knowledge is then not necessarily the main driver of ecosystem adaptation to climate change. Rather the effectiveness of governance institutions often plays the strongest role (Shkaruba and Kireyeu, 2013).

Given the constraints of the broader social and political context in which environmental governance institutions must operate, researchers have turned to

investigating strategies that can facilitate their effectiveness. Gunderson and Light (2006) define adaptive governance as the institutional framework that deals with social and political dimensions of resource management and that allows adaptive management to function. Brunner and Steelman's (2005) research suggests that adaptive governance is a workable model for creating "dependable knowledge that is relevant and timely for decision-making purposes and more efficient given the real-time demands in some circumstances."

3. MANAGEMENT MOSAIC

"Middle Rio Grande" is defined in this thesis as the areas adjacent to the 250 km reach of the Rio Grande from Cochiti Dam to Elephant Butte Reservoir, consistent with definitions from the US Army Corps of Engineers and the Bureau of Reclamation.

3.1. Middle Rio Grande bosque ecology

In arid and semiarid regions, riparian forests along large rivers function as high-diversity "hotspots," providing critical corridors for migration and distinctive habitat. Floodplains of the major rivers of western North America were historically broad and meandering. River channels migrated with regularity as geomorphological and hydrological processes played out, unchecked. Human intervention on the hydrology of rivers in the form of dams, levees, irrigation canals, diversions and groundwater pumping has narrowed the historical range and diversity of habitats of the floodplain (Richter et al., 1998).

Though narrowed by human land use, riparian gallery forests have persisted along some rivers of the western US while much of the associated herbaceous wetlands, fluvial marshes, wet meadows and ephemeral ponds have not, as the hydrological and ecological connection has often been lost between river and floodplain (Ward and Stanford, 1995). The Middle Rio Grande floodplain represents one such altered landscape.

Since completion of Cochiti Dam in November 1973, peak annual discharge has dropped from an average 225 m^3/s to an annual mean of 150 m^3/s at USGS gauge 08330000 at Albuquerque, New Mexico (Shah and Dahm, 2008). Lack of saturation and disturbance due to regulated spring floods has resulted in floodplain drying and reduced recruitment of *Populus* species, the native woody plant that is a characteristic of the large rivers of the western portion of the United States (Friedman et al. 1995; Katz and Shafroth, 2003). In the semiarid southwest, the Rio Grande cottonwood gallery forest, or "bosque," is visually dominated by *Populus deltoides* var. *wislizenii*, with a diverse woody understory community historically including *Salix exigua* (coyote willow), *Baccharis glutinosa* Pers. (seep willow), *Amorpha fruticosa* (false indigo bush) and *Forestiera neomexicana* (New Mexico Desert-olive). Nonnative woody species have been introduced to the area, two of which have become the third and fourth most abundant woody plant species along the rivers of the western US: the *Tamarix* species (saltcedar) and *Elaeagnus angustifolia* (Russian olive; Friedman et al. 1995). In its relatively short history as a dammed river, the Rio Grande has become a highly modified and intensely regulated

body, and the associated bosque ecosystem structure and function are consequentially altered.

3.2. Historical human use of the bosque

Human settlement of the Middle Rio Grande likely began with Chacoan ancestors of the modern Native American Pueblo communities who now live there (Phillips, Hall, and Black, 2011). Prolonged droughts repeatedly lead to migrations of people with knowledge of subsistence agriculture to find new sources of reliable water (Debuys, 2011). The migrants' already sophisticated irrigation practices were adapted to the spring snowmelt flooding that saturates the floodplain and summer monsoonal rains that provide relief from the dry heat of June. Today, the Pueblo communities of New Mexico are geographically concentrated along the Rio Grande and traditional subsistence agriculture is supported by irrigation from the river.

Western colonization of the region by Spanish Conquistadors began in the middle of the 16th century. Land was granted to early settlers by the Spanish Crown. These settlers established villages adjacent to many Pueblo communities along the Rio Grande for easy access to river water, which was needed to support their many agricultural endeavors. Spanish settlers introduced a system of irrigation and communal water governance known as "acequia agriculture" that relies on diverting flow from a perennial stream into a system of commonly owned ditches on the floodplain. The diverted water is shared among the members of the acequia. Livestock brought by the Spanish generated widespread and long-lasting disruption to the existing vegetational regime, including impacts to the Middle Rio Grande bosque (Dunmire, 2013). New Mexico became a territory of the United States with

the Treaty of Guadalupe Hidalgo of 1848, initiating the next influx of colonization, this time by American settlers of European and African descent – homesteaders, miners, and ranchers. The recent history of the Middle Rio Grande was largely influenced by east-west interstate corridors: the Atchison, Topeka and Santa Fe Railway in 1880, Route 66 in 1937 and Interstate 40, completed in 1984.

In the context of rapid global climate change, the Middle Rio Grande valley is positioned to experience significant social and ecological disruptions (MRG Climate Vulnerability study, Benson, Llewellyn, Morrison, and Stone, unpublished report), with implications for regional and natural resource planning.

3.3. Habitat restoration in the Middle Rio Grande

The Bosque Biological Management Plan of 1993 intended to set the stage for a new era in Rio Grande management – to be the "first step toward restoring the Bosque's health" (Bosque Biological Management Plan, 1993). The plan was authored by a conservation committee appointed by US Senator Pete Domenici and was primarily directed at resource managers and decision makers, with the purpose of alerting them to the system's condition, identifying the challenges to its biological quality and integrity, and outlining a path forward. The plan laid out methods for conservation and recommended procedures for an active change to biological management that might accomplish the conservation goals. The complexity of the management situation in the Middle Rio Grande was not lost on the authors, who were primarily research biologists.[4] The authors stressed the need for an integrated

[4] This plan reflects a time in ecology when systems theory was readily integrated into discussions of conservation planning and research ecologists were becoming

management approach with a central coordinating structure and an active, representative council of managers and concerned citizens. To make their case, the authors used data to develop a scenario of future conditions with no active change in biological management. Twenty-one recommendations were offered in the plan, including a structure for coordinating the implementation and maintenance of the plan. In the final report of the Rio Grande Bosque Conservation Committee (1993) (but not in the management plan), an adaptive management strategy was recommended to address the matrix of governance and administrative structure.

The 1993 management plan demonstrated a growing awareness that the Middle Rio Grande bosque's condition was seriously impaired and worsening under the pressure of the growing human population. That awareness was soon underscored when two Rio Grande species were listed as federally protected under the Endangered Species Act: the Rio Grande silvery minnow, *Hybognathus amarus*, in 1994 and the Southwestern willow flycatcher, *Empidonax traillii extimus*, in 1995. The Rio Grande silvery minnow's listing was attributed to dramatic alterations to the natural hydrograph and the Southwestern willow flycatcher's listing was due to loss, fragmentation or modification of habitat. The listing of these endangered species changed the institutional landscape of natural resource management in the Middle Rio Grande, with likely the most significant development being the Middle Rio Grande Endangered Species Act Collaborative Program (Collaborative Program) The Collaborative Program was established in 2000 to "strive for the survival and recovery of threatened and endangered species in the Middle Rio Grande while

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more involved with natural resource management. See Noss, O'Connell and Murphy, 1997.

simultaneously protecting existing and future water uses in compliance with state and federal law, including compact delivery obligations" (Collaborative Program website, November 1, 2015). There are currently 16 signatories to the Memorandum of Understanding, representing local, state, tribal, and federal levels of government, agencies, and interested groups. Administrative duties reside with the Bureau of Reclamation. The Collaborative Program is the major source of funding for habitat restoration, non-native species management, species population surveys, water quality, hydrology, and geomorphology research, and silvery minnow egg collection and propagation in the Middle Rio Grande.

3.4. Bosque Ecosystem Monitoring Program

The authors of the 1993 Bosque Biological Management Plan stressed the need for *monitoring* biological quality and ecosystem integrity, and *research* into the ecological processes and biotic communities – for both scientific and management-related goals (Management Plan, 1993). The Bosque Ecosystem Monitoring Program, BEMP, developed out of this call for long-term monitoring and research.

BEMP is coordinated by the University of New Mexico's Department of Biology and the Bosque School, an Albuquerque private middle and high school. Student volunteers from area schools gather long-term data and conduct research at 30 research sites along 560 km of the Rio Grande to study ecosystem response and function with an aim to inform policy. Data analysis is done primarily by BEMP staff at the university, though students have conducted their own research, and findings are shared at public events and presentations specifically for funders. Funding sources have varied over time, including public resource management agencies,

NGOs, foundations, corporations, and individuals. The program follows detailed protocols, with monthly core data collection that includes weather; precipitation; depth to groundwater; surface active arthropod activity; and leaf, wood, and plant reproductive parts as litterfall biomass. The first BEMP site was installed in 1996, and the mission has remained focused on science, education, and stewardship since the start. The program was recently honored with the 2015 New Mexico Governor's Environmental Excellence Award in Land and Ecosystem Stewardship.

4. METHODS

This study applied a grounded theory approach (Glaser & Strauss, 1967) for research design in order explore the question of what relationship exists between ecological monitoring data and natural resource management decisions in the Middle Rio Grande. This approach fosters the collection of study data without preconceived notions and applies that data to building a theory to explain the phenomenon where the existing literature is inadequate.

Primary data for the study came from 18 semi-structured in-depth interviews with land and water resource managers, biologists, and policymakers representing 17 entities with a stake in planning and management of the Middle Rio Grande bosque. Interviews were conducted in person during the 2015 summer; each lasted for 45 to 90 minutes.

Interviewees were identified through the combination of 1) a data-users contact list provided by BEMP, which was based on participation in past BEMP workshops or past contractual relationships, and 2) by asking interviewees who

else they would recommend including in the interview set. Interviewees were contacted directly and scheduling was at the willingness and convenience of participants.

Interviewees could be classified using the following three categories: manager, scientist, or policymaker. The roles of some interviewees could be represented by more than one category, but a primary category was selected for each. The category of 'manager' was used for those who have project management and/or administrative duties for a particular jurisdiction. Managers might be informed by a clear mandate, a board of directors, their own professional knowledge, or some combination of these, and they directly influence project and planning decisions for an entity. Ten of the 18 interviewees were primarily managers according to this definition. The 'scientist' category designates those who hold an advanced degree in a scientific field (e.g., biology, limnology, hydrology, etc.) and use this knowledge to inform planning and management decisions. Five of the interviewees fell into this category. The 'policymaker' category describes those who directly influence Middle Rio Grande bosque management policy beyond the project level. Three interviewees' duties were best captured by this 'policymaker' category. One interviewee's duties were captured by all three categories, but she was classified according to her primarily role as a manager.

Interviewees were asked questions about using ecological monitoring data for land management decisions. (See Appendix for sample interview questions.) Questions were asked to understand the use of monitoring data, including data collected by BEMP. Questions sought to make clear whether using monitoring data

for decisions is policy or standard procedure, and whether norms and attitudes toward data-informed decisions exist. Questions were asked to understand what makes it possible and not possible to use ecological monitoring data, including BEMP resources, for land planning. An objective was to learn about whether and how these entities use an adaptive management framework for decisions. Questions were asked to understand what is needed to improve sustainable land planning for the Middle Rio Grande bosque.

Other data reviewed included publicly available secondary data, such as workshop materials, newsletters, the BEMP database and BEMP reports, and published governmental policy documents, reports, and management plans.

Seventeen of the interviews were digitally recorded, transcribed, and coded.[5] I identified initial codes by systematically studying the text, looking for any information related to the use of ecological monitoring data for land planning and management in the Middle Rio Grande. Such statements were tagged with one or more codes to more easily view and analyze the large amount of data. Codes were added, combined, grouped, and refined by systematically studying the full transcript. This process was iterated until the codes captured all of the relevant data this study set out to investigate. The final set of codes fell into three themes of used/useful information, decision-making context, and facilitating informed decisions.

[5] The outlier was with an interviewee from an entity with an important perspective on the topic, but that wouldn't permit this to be a recorded, transcribed interview. Instead, I recorded responses in notes following the interview.

5. RESULTS

Interviewees described the realities of making sustainable land management decisions for the complex Middle Rio Grande bosque ecosystem. The three themes that emerged from the data are used to discuss the results of the 18 interviews below. Within each theme, subthemes are used to organize and present the findings.

5.1. Used/Useful Information

5.1.1. Data sources other than BEMP are primarily project-specific and not widely available to managers

Interviewees described ways that the BEMP record has helped decision makers to recognize trends, inform baseline conditions, and track changes following project implementation. In the current context of public entities pressured to be efficient and thrifty, BEMP provides monitoring data that are publicly available and with the potential for use in management decisions. By these accounts, BEMP provides data that would otherwise represent a cost to these public agencies.

Responses from 15 entities indicated that BEMP is unique as a resource for conservation decision making because it appears to be the only long-term ecological monitoring program covering the Middle Rio Grande. Interviewees said that BEMP contributes a record distinguished from any other by its regional scope and long-term design. One manager described how she sees BEMP data as compared to other similar types of sources this way:

> I don't know that I'd call it [the other sources of bosque ecological data] comparable – it's more limited in geographic scope and somewhat different

> in the scope of monitoring and time wise [sic]. BEMP has a long-term dataset, and they monitor the same things every month. Most of the other monitoring occurs as a part of specific projects, they have a beginning and an end date, and if some of it can be continued then they do, you know the Hink and Ohmart monitoring is an example of something that's long term. We've tried to…[names a particular entity] especially is trying to fund some other things on a long-term basis, but other things are project specific. Like the restoration projects that are done as for endangered species habitat, those tend to be monitored for a particular amount of time and then turned over to the endangered species program to be intermittently monitored, so that's the way things go. You might get things that you wouldn't get from BEMP, like geomorphology, but then BEMP has sort of a larger rotation like you wouldn't get woody debris, or groundwater chemistry or arthropods, leaf-fall, from other monitoring programs.

Interviewees indicated that decision makers experience an overall lack of long-term studies relevant to their management goals, making BEMP's record particularly useful when no other information is available. Although other ecological research studies do exist, only three of the 18 interviewees mentioned them as sources of monitoring information that they have used to inform management decisions.[6] Some interviewees described relying on BEMP data because of the lack

[6] Two long-term studies of fuels reduction and wildfire effects in the Middle Rio Grande bosque have recently informed local bosque management planning (e.g. Corrales Bosque Preserve Wildfire Protection Plan, 2013). The US Forest Service

of other ecological information when initiating a design process, as this manager explained,

> We didn't have any one out there collecting data. The only decisions that we were able to make were based on models, and, like, data from other areas and it was only because of citizen science – who would come out and collect data that we could ground truth what we were seeing in the models, so it's also a great way to move projects forward when you don't have a lot of resources. We don't have an army of biologists to go out and collect data, we just have models and they are getting better and better all the time but we cant just depend on models, we need someone to go out and test it. "Okay high school kid go out and test it. Is it three feet? Okay, my model is accurate?" Or, "no it's not; maybe I shouldn't use that for all of my decisions."

Interviewees said a major reason for the lack of other sources of monitoring information is most monitoring was done to satisfy compliance and reporting requirements for particular habitat management projects. The following statements demonstrate that some interviewees viewed monitoring as bound up with project-specific requirements:

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worked with a number of partners to conduct an ecosystem-wide experiment to evaluate the outcomes of fuels reduction treatments in the Middle Rio Grande (Finch et al., 2008). Decision makers could also look to past studies of non-native removal and controlled flooding studies conducted at the Bosque del Apache National Wildlife Refuge (McDaniel and Taylor, 2003; Sprenger et al., 2002).

> [Monitoring] depends now on the project. Almost nobody monitors if there isn't a requirement [to monitor].
>
> It turns out that unless you have regular staff to do that [monitoring] on an ongoing basis, it only happens by hiring a contractor to go out and do that vegetation mapping, or by partnering with other agencies. So… you look at who's collecting information and you share it. One of the great things about BEMP [is] where I'd have to have several employees out all of the time to replicate BEMP's efforts...We do monitoring now, we have people with biology backgrounds, but we don't have just a staff biologist. We have people with science backgrounds… Not really a specific monitoring plan. We have metrics that we adhere to that are things like plants planted and acres restored, reporting or performance measures [that are] not geared to fine grain. [It's] unlike more biological monitoring [which] is at a whole different scale.

When asked if other entities are doing monitoring at the level of BEMP, another interviewee responded,

> No one is, including me. We're always looking at what others are doing and looking at what we can do to supplement. We determine

what we need to collect based on what others are collecting – either to supplement or to compare or confirm.

Interviewees from all 13 participating entities that have management jurisdiction for bosque land said that the specific requirements for habitat restoration projects are a factor in their level of data use. Since habitat restoration projects are concerned with federally protected endangered species and involve working in the federally regulated river, they are subject to NEPA. One manager explained, "If there's a restoration component to the project, then yes, we do try to do some kind of data collection to make sure that what we're going to do is going to be successful...There can't be a BEMP site everywhere."

Interviewees said that a more comprehensive approach to monitoring was pursued in the past. One manager recalled a time when relevant decision makers were "building this organized monitoring database and the [Collaborative] Program made some steps toward that in the past, but then things kind of fell apart or didn't happen." As of this writing, the Collaborative Program's monitoring plan exists, but, in the words of one interviewee, it has been "managed in more of an ad hoc manner." A database exists on the Collaborative Program's website, meant to be a repository for information such as monitoring data, but was not mentioned as a source of information by interviewees.[7]

[7] There are current developments with the Collaborative Program that may result in an integrated approach to ecological monitoring and data storage. Another program (Forest and Watershed Health Institute) is working to consolidate existing monitoring data for the Middle Rio Grande to be available to decision makers.

A factor contributing to the lack of long-term monitoring records that interviewees noted is the nature of contractual agreements. BEMP is financially supported through a range of agreements, including contracted data collection. As an environmental consulting firm might be hired to do a specified study, BEMP contracts to report its findings to land managing agencies. Whereas monitoring information from other contractors is proprietary, BEMP insists that its reports will remain publicly available – information derived from a BEMP contract is not the funder's proprietary information. Consequently, BEMP's record is the only one available to all bosque land managers that offers long-term and regional information. BEMP's monitoring information is used because it is available.[8]

5.1.2. BEMP information improves professional knowledge

Thirteen of the 17 entities represented in the interviews have jurisdiction over some amount of bosque land and make management decisions about that land. (The remaining four influence bosque land management via policy or are critical adjacent land managers.) Of these 13 land-managing entities, nine reported that they have used BEMP data as a source of ecological information when making management decisions. One more is waiting on BEMP data, which they plan to use, and two said they would be looking for chances to use information from BEMP soon.

[8] BEMP's approach highlights the fact that not sharing monitoring information works to maintain existing data gaps. This is a challenge tied to market economics: if the information contractors were hired to collect by one entity were shared with all entities (as it is with BEMP), there would be reduced demand for contracts with other entities because they have already enjoyed the benefits of the shared findings. The result is that there might be another long-term record that could be constructed with monitoring data other than BEMP data, but it is dispersed and inaccessible.

Interviewees from these nine entities described different levels of use of BEMP information. Those who have learned how to apply BEMP data to their needs reported a high level of use (and efficiency), as described in this example:

> During the planning stages [my colleague] was drawing on those datasets to help develop the existing conditions report and to be able to project how the management features should affect the BEMP sites. So, having the BEMP sites already made them attractive for restoration projects, especially having the depth to groundwater. I think some of that data helped with siting those projects…We can use [BEMP data] to describe the existing conditions – so from a NEPA perspective – and for post-project monitoring. So if we locate a project on or near a BEMP site, we expect to see some kind of effect in the BEMP data. If we have a specific need for more data, we might ask BEMP to do that. The process would've been pretty different if the BEMP site weren't there, like, we would've hired a consultant to do that data collection for existing conditions.

Interviewees described a mutual incentive for BEMP sites and restoration sites to co-locate, which results in learning on both sides; managers have more information to draw upon to evaluate the performance of a project if a BEMP site is there, and restoration sites create opportunities for research that educates BEMP student participants about responses to management and BEMP staff can analyze ecological change following restoration that may inform stewardship. BEMP monitoring data

helps land managers address a wide variety of questions. Interviewees said that they refer to BEMP data for diverse reporting needs. One scientist pointed to BEMP's long-term hydrology dataset, saying that it "is useful for trying to decide where some of the habitats would be most sustainable." Another described using BEMP data to evaluate the effectiveness of restoration techniques. BEMP reports and presentations influenced this manager: "We have adapted our prescriptions over time based on what we've seen on the ground and BEMP has definitely played a role in that because they've established BEMP sites in several of our restoration sites to track how those things have gone."

Ecological monitoring data influences management decisions only to the extent that the data actually improves professional knowledge. Nothing ensures that a decision maker will believe the information that they access. One interviewee explained,

> BEMP is one element in a multitude of elements… That's where professional experience has to – will hopefully – play a role. What you'll see is that range of professional experience varies widely, within an agency and across agencies. Yes, [discretion], that would be one good term to add to it. Yes, the discretion to either look at a narrow range of functions or a broad range of functions. Some [decision makers] are very focused and remain very focused, but some can acknowledge new information and bring it in while keeping their focus. Some will not even acknowledge the importance [of new information].

Because consulting ecological monitoring data is not explicitly required to aid in decision making, the degree to which a given decision is science-based, or not, has a lot to do with the knowledge of the professional making the decision and how they choose to use it. Given the abundance of constraints on these professionals (detailed below as barriers), making science-based decisions more often means becoming familiar with the issues than testing a hypothesis. For such a person, a lack of information can mean he or she simply must make the decision based on less information. BEMP works to address this lack of information by sharing with decision makers the interesting and relevant findings in their data through reports, workshops, and presentations.

Also challenging for some decision makers was not only finding data and getting informed, but determining whether they needed to become informed by monitoring information to be able to make a given decision. Interviewees from 11 of the 13 entities managing bosque land indicated that they were unsure whether they knew when data was necessary to be able to make a given management decision. However, one scientist made clear this was not a challenge, saying,

> Adaptive management should identify which decisions need monitoring, but we don't have the budget to allow [adaptive management to inform] all decisions. When it's [the decision] going to have an effect on the ecology is when it must be made using monitoring data. That makes it possible to use BEMP data for management decisions. We review BEMP reports and they

> have some presentations. So, right now, it kind of informs our expertise and we keep that in mind when making a decision.

Another scientist responded without the level of certainty conveyed in the quote above. Like ten other interviewees who felt unsure about when they need to consult ecological monitoring data to make a decision, she replied,

> That's a hard question. It depends. If you get into a situation where you have something beyond what you've seen before, like the hydrology or geomorphology is weird there [then I would know that I need to use monitoring data to help me make the decision].

Interviewees readily linked the importance of monitoring information to learning about the system that they manage and can have great influence over. One scientist felt that monitoring information was essential in learning revelatory lessons about the managed bosque system, saying, "definitely… often the monitoring information that we come up with has radically changed our knowledge."

5.2. Decision-making Context

5.2.1. Barrier: Lack of time or appropriate staff to consider data

All 18 interviewees identified the lack of time or appropriate staff to consider data as a barrier to their use of monitoring information to inform decisions. The experience of this manager is typical:

> The biggest barrier that I'm running into on my end, with the capacity I currently have, [is] to spend time looking at the data...I need more staff…Right now, I'm looking at it just on the surface. I get to look at their report. I try to ask a couple questions. That's about as far as I get. I would really like the time or a staff member to be able to look at our reports more in depth, for trends, and look year after year to be able to compare our site to other sites. Right now, I get to read the report.

With limited time or ability to consult with ecological information, the norm can be established that one only consults with data only when it is required. However, interviews suggest that decision makers tended to regret their lack of time or ability to become more informed. Public land agencies have their own momentum; interviewees said they must maintain certain minimum standards for their decisions without letting the project opportunity pass. As this manager explained,

> Sometimes you're running behind and trying to catch up on projects. We get approached a lot and people want to spend money on our property and sometimes you don't have the time to do the real analysis to test that kind of decision [about the best use of the offered money]. You know, it's more like we look at some maps, we go on the ground and see what's there and decide, do we want to work there. I always do a check for endangered species nesting; I always do that to make sure we're not going to run into those kinds

> of issues [that result from disturbing the endangered southwestern willow flycatcher].

All 13 interviewees from bosque-managing entities expressed some level of regret that they must make decisions without the time they would like to have to inform themselves.

5.2.2. Barrier: Funding drives priorities

All 18 interviewees noted that sources of funding have a high degree of influence on management schedules and priorities. This becomes a barrier to data-informed management decisions insofar as it infringes on decision makers' ability to address their own management questions or pursue known management objectives. Mangers said they hesitate to initiate a monitoring plan because they can't foresee what projects they will be implementing and, therefore, don't know what their management questions will be. One manager summarized:

> Right now we have funders and other people driving the projects that are being done and the monitoring and it should be the other way around. And I think a lot of the scientists in the bosque would agree with that. [We need] to have more of a focused monitoring plan, to make sure we're covering the bases, rather than piecemealing according to the programs and funding.

Interviewees said the level of control by funders limits their ability to determine the duration of projects that would help address management questions and reduce

uncertainty about the system. Public land managing entities often do not have the ability to re-allocate funds to continue useful projects initiated by outside funders. One manager said that if an organization with an interest in promoting science-based decisions approached his entity with funding for a useful project, it would only endure to the extent that the funder's money does.

Other managers said they were concerned about the future of funding for monitoring. A manager portrayed the attitude toward data of the past few decades as a series of challenges, passing from 'how to manage the data' to 'how to inform managers with data,' to the current challenge of looking to grants to be able to fund the collection of data. Looking to the next ten years, he remarked,

> Grants were still pumping money into that soft market for getting people back to work since the recession. Now we're starting to get into the pork barrel. We're seeing a thinning of our funding and the first thing to go is data collections. If I say I cleared 20 acres of salt cedar, that's a 'do' that [reporting the collection of data at] sites isn't."

This view to the future results in additional uncertainty and disincentive to initiate the kinds of programs and studies that facilitate learning among land managers. Without predictable funding for monitoring, management choices can stagnate around a few proven practices and mangers hope these continue to not fail them. The manger quoted above also indicated another disincentive for learning driven by funding issues: when entities must find separate funding sources for the design,

implementation, and monitoring of major management interventions, day-to-day costs escalate because their demands on staff increase.

5.2.3. Barrier: Lack of requirement for evidence-based decisions

Interviewees from 16 entities suggested that the lack of a requirement to use ecological monitoring data for bosque decisions poses a barrier to data-informed decisions. Generating and reporting ecological data is required for habitat restoration and some other projects. Interviewees reported few other instances in which they must consult monitoring information.

Interviewees noted that the internal norms and policies about what makes the path to a decision satisfactory at their organization could be very different from those at other entities. The range in variation in these norms and policies was evident in the range of statements made by interviewees about the importance of monitoring data in carrying out their jobs. One scientist's response provides an example of how internal norms and policies can lead to a high level of data-informed discretion:

> [Monitoring fits in] always at least initially. "Is there any data on this site" [Am I] able to look at a similar site?"[We] always do some sort of monitoring so that's always the first step. It's "what data do I have for this site and what are the gaps? What do I need before we can even start to be able to compare?" And I can't always get everything, especially when trying to do projects in a shorter timeframe, if they are smaller projects.

When I asked another manager if it was the case that there was no decision that would require him to use ecological monitoring data, he said, "I would say that's accurate because of the 'requires,' but it certainly helps." However, some interviewees offered examples of when a decision would certainly require ecological data. It is noteworthy that these examples often cycled back to the project-specific requirements of habitat restoration, as evident in these statements:

> [You definitely need ecological monitoring] when it's clear you need rigorously collected data. [And when] you need to demonstrate there [was] not a negative effect on the habitat. Then you have to hire a contractor to go out and set up transects and do the thing objectively. If it were up to me, I'd have a whole team to do what the contractors do. If I could, I'd add a quarter million to have that team.

> Without that [monitoring] information, I cannot justify spending hundreds of thousands of dollars [because] we don't know if there was a change. Even [with] that pre-monitoring, [I'm] able to show, "look we have a degraded riverbed."

> We try to incorporate that and I don't know how well other agencies try to do that. In the past [my agency] has handed over the keys after we do the projects. We are moving more toward - we need the adaptive management. We need the monitoring to make sure that not only did we design a good

> project but that it continues to function and that's coming from the headquarters probably in response to "Okay we need to be doing this right." And that means monitoring it and collecting the right data to evaluate it and if we need to do anything, what we need to do?

To contrast with those project-specific requirements, decisions that have no requirements for use of monitoring data can result in a spectrum of discretionary consideration of monitoring data. If the constraints of the decision-making context are high, less information is used. I asked one manager, "If no ecological data exists for a site, is none used?" Her reply: "Yep, pretty much – we go on the ground and see what's going on" suggests a pragmatic simplicity, but also obscures what these same decision makers lament: managers cannot prove that they are making better decisions without a mechanism for quantifying change.

Fourteen interviewees mentioned that a requirement to consult monitoring data was lacking and/or would improve their decisions. Four of these 14 said that their entity had a protocol for when ecological data must be consulted for a decision. A protocol was described as a source of relief from political or ideological pressures, as reported by this manager:

> Before we had this tool, biological review was completely random, all discretion. [Biological review happened] if the biologist caught wind of it and was interested in it. There was nothing in place if we were destroying wetlands systematically one at a time and we need to stop that.

The chance to imagine a requirement to consult monitoring data for certain decisions captured the attention of some interviewees, who took the opportunity to play out what the implications might be. One policymaker imagined this:

> I heard myself say that, "requiring this," and I don't know if I can advocate another requirement for land use planners. But I still think it's something that ought to be done. And attention has to be paid to it and we aren't [paying attention] enough. Depends now on the project. Almost nobody monitors if there isn't a requirement… What would that really look like? They [the land use planners] might be grateful. They could say there's evidence that what we're proposing to do will come out right based on this other project so litigation could be less of a pressure. It [a requirement to consult monitoring data] could make their [land use planners'] prescription easier.

One manager summarized a frustration, noted by several interviewees, about the large amounts of monitoring data that is collected by various land management entities to satisfy project-specific requirements (data that is usually proprietary information), and through the Collaborative Program's monitoring efforts (usually shared with Collaborative signatories). She felt that, because there is no mechanism to ensure that the monitoring data is used, it takes a long time for monitoring data to contribute to learning:

> Is the monitoring being used or is it just a waste of time? We end up learning after a long enough time, but if there were a feedback of requiring it to be used, would we learn more? I do think so. I think it's wild that we spend so much time doing projects and monitoring and then to not use that information.

5.2.4. Barrier: Available information not immediately useful

Interviewees from 16 entities said they sometimes could not use the ecological monitoring information available to them, including information from BEMP. Land mangers reported that they might not be able to use information for reasons such as the data format; lack of data analysis or interpretation; the analysis is not according to the scale of interest; and the available data does not address management questions.

Interviewees tended not to use available ecological data that had not been analyzed. Consulting raw data in spreadsheet format seemed to increase uncertainty among some decision makers. As one manager clarified, this does not mean that raw data are never used, but the additional data analysis makes it much more likely that it will be used for decisions:

> I definitely, definitely need [analysis]. We rely on other people to do data analysis...Right and that's more helpful to me. I mean there are times when we might look more closely at their data to draw our own conclusions for some things…but having the results summarized -- and graphed particularly -

> - is helpful and it gives us a picture river-wide rather than just at the sites [that we manage].

One manager described just how critical receiving a recent report from BEMP was for using the ecological information:

> That's why being able to have BEMP produce things [analyses] for me makes it easier for me to use. If I had to go do the statistics, draw up the graphs or whatever, it would still be on my desk and not being used. So having them make those reports, and even sitting down with me and say, "here's your report and the things we saw that were different," made a world of difference.

Eight interviewees identified the lack of annual reports from BEMP over the past several years as a barrier to using that source of ecological monitoring for management decisions. BEMP has continued to publish the raw datasets over this period, but the precedent of a report complete with analysis and discussion available for free to the public has not been maintained since 2012. Interviewees said the value of data analysis from the BEMP science team was a major influence on whether BEMP information is useful for management. Some decision makers do not have the kind of science background needed to do the data analysis using BEMP's raw data, yet use BEMP's raw data to make management conclusions. This leads to potentially incorrect interpretation of the data or interpretation that is strongly

biased. As this manager described, when BEMP does not provide a scientific analysis of BEMP data, decision makers can use that data for their own purposes:

> I'm looking at the raw data and having to determine my own pattern independently from some other person who's making another claim about something. I'm just looking at gross patterns. It's not super sophisticated, not multivariate.

In the view of at least one policymaker, "the group that did the monitoring, the fieldwork, should do at least the initial analysis" as a means of quality control. This issue is tied to study design: BEMP collects the data it has determined is needed to estimate ecological change in the bosque at a high degree of detail, and has used appropriate methods of analysis for presenting these results to the public. When the analysis from BEMP is no longer provided, interviewees not trained in statistical analysis said they find it difficult to interpret BEMP data, especially when attempting to answer management questions. For example, a few interviewees said that, for BEMP data to be useful to them at all, they want BEMP scientists to make management recommendations:

> Yes many of us can do that [data analysis] work, but we just don't have the capacity to do that analysis. The connection would need to be made for us…This is really great data and it would be really helpful to have it summarized and tell me how to use it. I need [BEMP scientists] to call me and

> say “can I bring it to you” and “I’d like to propose you guys do a project and here’s where you should do it.”

Other decision makers said they would be uncomfortable with management recommendations from BEMP scientists, but they want more large-scale, management-relevant analysis from BEMP to inform management policy. The lack of reach-wide analysis, identified by 12 interviewees, was summarized well by one manager. He had participated in additional (reach-wide and question-driven) data analysis with BEMP that he felt was more useful than any previous information from BEMP:

> I really liked seeing the results of what they are getting over a large scale and it’s really, really cool. We got to see changes on that gross level. If I’m having the die-off, [BEMP]’s able to show where else that’s happening. They could be showing ecological amplitudes. What’s an average bosque? How many cottonwoods per acre? Russian olive? And they have the ability to show the median stems per acre, [and] how some sites were responding, versus others. We can’t do that. [Other land managers] can’t do that. So that’s cool. Not many places have the ability to look at that kind of a large scale.

This manager went on to clarify that what he thinks is missing is not BEMP “scientists acting as advocates for certain management approaches,” but analysis that allows decision makers to make their own evaluations of their management

decisions based on the ecological outcomes. Interviewees that commented on the topic agreed that BEMP should influence policy through analysis of ecological trends relevant to bosque management decisions.

5.2.5. Barrier: Leadership priorities influence the position of science

Some decision makers said that unpredictable leadership priorities constrain their ability to make science-based environmental decisions. Interviewees from 16 entities said that the level of influence that leadership priorities have sometimes operated as a barrier to considering ecological monitoring data for decisions. For some, their leaders encourage the consultation of monitoring data, as when a federal agency has thoroughly adopted a policy of using adaptive management. At those agencies, interviewees said that their leaders expect them to substantiate their management decisions with science. One scientist had witnessed the change in attitude toward the position of science at her agency and the resulting increase in consulting monitoring data:

> There's been a definite shift. The older folks saw environmental regulations come about in their careers. The folks that are coming…now it's more the norm that you have these regulations. Because of that, I think the adaptive management and applying the lessons learned is becoming more the norm. And that's totally making generalities. Makes it easier to apply the monitoring information to decisions, even if it isn't required. Who's at the helm matters.

One interviewee described leadership priorities that explicitly limited the influence of science on management decisions:

> We have been told by this administration that we are not regulators. Even though I know there are 31 species of concern [in New Mexico], I can't require that we work around those.

Another manger said that her board of directors was interested in what scientists report about the bosque, "because the scientists have more weight in ecological decisions, but they don't necessarily outweigh political decisions." When the ability to make management decisions faces a barrier like political and ideological agendas trumping scientific findings, some interviewees said they have created data-reliant decision protocols, rather than follow the political whims of their leadership.

Leadership priorities can exert influence that sublimates the position of science by specifying or asserting the purpose of the organization and restricting resources that do not directly serve the stated mission. One scientist had witnessed this, but described a shift in the agency:

> Our definition of success first is according to our mission… And part of that – we've had a shift, in that we plan to put those environmental concerns into the projects we are doing. An ultimate success for us as far as a mitigation project is "Did the wetland come in as we planned it to come in?" Or "How is the bird habitat. Are the birds using it?"

Unpredictable leadership changes can also constrain the motivation to put resources toward a long-term monitoring program. This was true for an entity with a director who makes clear her commitment to habitat restoration and prioritizes those projects for her staff, but the interviewee remarked, "When she leaves, that may all change." Another interviewee said that an adaptive management approach would not be appropriate for his entity because a board of elected officials subject to yearly changes provides direction. According to this interviewee, reporting to a board of directors entails "a bunch of short term goals" and the need to select information that addresses the concerns of the current board.

5.2.6. Citizen science is not a barrier

The responses from all 18 interviewees indicated that BEMP being a citizen science program was not a barrier to using BEMP information for bosque management decisions. Responses suggest wide agreement that BEMP information is high quality, but reasons for confidence in the program were diverse. All interviewees emphasized that BEMP's reputation, as a source of scientific information, was solid. One manager said enthusiastically, "It's very consistent…[They] have set that bar very high. I trust them more than I trust myself."

Some based their confidence in the data quality on the oversight provided by the BEMP technical staff, as one scientist noted:

> Their primary mission is education – not that that impacts the quality of the data – we trust that because of the people overseeing it… Given the track record and that it's overseen by scientists, I don't think there are any questions about the quality of the data. If the science team at BEMP says this is good data to use on this project, then we want to engage them and trust their judgment.

Other interviewees pointed to the neutral position BEMP is able to keep as an academic team in the midst of an evolving environmental policy discussion. For instance, this manager said:

> They are independent. I've never felt as though BEMP had an axe to grind and a point to prove. They've always been above board and beyond reproach as far as their independence goes. [They] aren't out there taking info down to try to get up against somebody, but for the love of observational science. Their independence is gold plated.

A few interviewees indicated that BEMP has achieved its credibility over time by creating a track record. As this manager explained:

> I think citizen science is really important and need more of it. BEMP is respected [and] has a track record. Yes, we understand who's collecting the data, but there's quality control and it's a matured program. It stands on its

> own. Nothing wrong with citizen science, but sometimes quality control… need to have scientists there to question the data and ask "does it make sense?"

Still others said they rely on their own ability to discern reputable science and look to the data as an indication of its quality. A manager explained that,

> They [BEMP] are just different. I know they have to sometimes defend themselves. And they have proven that – that they are doing things that are just as good as any other agency.

Some entities distanced themselves from the citizen science aspect of the program and said that they treat BEMP the same as a contracted agent for data collection and reporting, as this scientist suggested:

> For us, BEMP is a specifically contracted action. The fact that they use [education] as part of it, that's great, but the fact that it goes to technical staff for the actual analysis –that gives us the info that we use.

In the majority of interviewees' statements about BEMP as citizen science, there was some indication that, although BEMP has proven itself (its place of high repute has been earned), its reputation doesn't immediately extend to other citizen science projects overseen by organizations other than BEMP. However,

interviewees also said that citizen science in general seemed more appropriate to consider as a source of information for decisions because of their positive experience with BEMP.

5.2.7. Decision-making protocols, including adaptive management, support the use of monitoring data for decisions

Interviews suggest that the ability to make environmental decisions about the Middle Rio Grande bosque is limited primarily by the five barriers given above. Interview responses indicated a single, broad driver that permits decision makers to consult science for management decisions: presence or absence of a protocol for environmental decisions. Seventeen interviewees said that they know what adaptive management is and discussed its relevance to their management. Of the 13 land-managing entities represented in these interviews, three have adopted an adaptive management approach to habitat restoration, and two others have some experience applying an adaptive management approach to decisions. These five entities reported a high level of ecological monitoring data use for decisions, and also require scientists to make decisions for habitat restoration projects. Another entity uses a science-based decision making protocol other than adaptive management and reported a high level of data use for decisions. A seventh entity uses a protocol based on qualitative assessment, described as "a subjective assessment of how good things seem to be going" using a descriptive framework.

The three entities that have a formal adaptive management protocol have a structure for making decisions, but reported that adaptive management does not address all concerns. Interviewees said the usefulness of adaptive management was

limited by the phase of their current projects and available resources. These managers anticipate that adaptive management will be more necessary in future management, but won't expect it to be without challenges. One manager observed,

> The challenges for adaptive management are well known; we aren't sure how much control we really have. We are kind of feeling our way through it. In the meantime it's important that we have the long-term data and continue that. The combination of the [improved Collaborative Program] database and BEMP should provide that.

One challenge evident in the interviews is that manager discretion still determines adaptive management insofar as the manager must decide which actions require an adaptive management framework. As one scientist pointed out, the choice to use adaptive management is very closely related to the choice to use monitoring data; both come down to whether the decision is based on evidence. He explained,

> I would look at it as "what's the appropriate level of adaptive management for a specific project." I think it's always appropriate insofar as it's testing a hypothesis: "did I get the effect I was looking for?" If I did then I'm not doing much except for maybe more monitoring. If I didn't then I've got to work out the next process or hypothesis what do I need to do to make that work. But also, "what do I need to look at to be able to evaluate that?" In that regard I

see adaptive management as always appropriate because it is just that scientific process of "did it work or not?" and how to follow through.

5.3. Facilitating Data-Informed Decisions

5.3.1. More immediately useful information

Interviewees from 16 entities said they want more or different information from BEMP and many went to lengths to describe what information would be more useful.

Annual reports from BEMP seem to provide the basic data analysis, without which 16 interviewees said they face a barrier to using ecological monitoring information for decisions. Eight of these 16 said that the lack of BEMP annual reports for the past few years contributed to this barrier. One manager stated that,

> Definitely having the data summarized and graphed and some comparative analysis – that really helps. And they do do that. I just don't know if they do it all the time.

For those who were not aware that some annual reports were not available, interviewees sometimes mentioned "more analysis" of data from BEMP as desirable and useful information, saying this would influence their current, casual approach to analysis: "Now we're just looking at the variability and making some conclusions based on that."

Interviewees also said they would like to see more data analysis that attempts to address management questions. One manager stated that, "it would still be helpful to do more review of implications of management actions or inactions. [It's] extremely valuable for that kind of information to be coming out. They have biologists that can assimilate the information because the program has matured to that point." Interviewees recognized that BEMP's dataset was perhaps the only record that allows for the site-to-site comparisons that would allow decision makers to determine which practices have desired ecological outcomes. One manager described this as a resource that no Middle Rio Grande entity could duplicate:

> It's the gross data collection that most of us are missing. We have a lot of the detailed stuff and could really use the large-scale stuff. And that's the thing that restoration ecology has been looking to create more of… And they [BEMP] have the ability to show the median stems per acre, how some sites were responding, versus others… Would be cool to see [my] site related to other sites, but that goes back to the gross accumulation of data. They do that about some sites. They've done that with some other sites. It's looking at it on the grand scale. I want to see the whole pie, not just my slice of it.

Interviewees indicated that they wanted to learn more from the ecological monitoring record, but were too constrained by limited time or staff to be able to analyze the BEMP dataset according to their management questions. One policymaker had witnessed this need (with BEMP but also elsewhere) and said that

monitoring programs "need to have summaries of the monitoring available…at a level of detail that would make sense for decision makers and managers." Interviewees suggested many specific examples of the kind of analysis that would be most helpful to them in reducing uncertainty. A few interviewees said they knew that they could ask BEMP to do the kind of analysis they wanted, but they didn't believe BEMP had the programmatic capacity to do it. One manager said that shorter-term research projects, done at the request of land-managing entities in recent years, have demonstrated BEMP's interest in answering management questions. He said, "how we go from the first 20 years of BEMP to the next 20 years will be by having that long-term research be bolstered by some of these short-term experimental research questions."[9]

The interviewees from the two entities that did not express a need for more useful information represent one policymaking entity that had worked with BEMP in the past to study specific resource concerns and one significant land managing agency. Interviewees from the land managing agency noted only that having direct access to the complete BEMP database would be a useful improvement, since their jobs require doing mostly original data analysis to address their management questions.

[9] For some entities included in this study, financial support to BEMP was based on contractual grounds, the terms of which vary from one to another. While one entity would have assured access to the BEMP database as a deliverable (interviewees said they all data is not available on the BEMP website and they must sometimes contact BEMP), another might expect annual reports and a presentation summarizing findings (that were generated for that particular contract, but not available to others). Interviewees expressed understanding that BEMP was under many different obligations that would be difficult to meet, but noted that those agreements were critical to maintaining funding.

5.3.2. Increased communication

All 18 interviewees noted that increased communication from BEMP would help make BEMP more relevant to improving bosque management. Interviewees often expressed remorse or embarrassment that they would be asking for more effort from BEMP, acknowledging the program's many demands and limited funding. All interviewees noted BEMP's educational role as important to the wider community and/or demanding of the program's communication resources.[10]

A manager with an entity that manages bosque land said that increasing the level of communication from BEMP could be essential for continuing funding:

> They are running a big project, with not a lot of staff. And for them additionally to be accountable to their numerous funders is not easy. So that kind of thing… it forces them to be accountable to give reports, presentations. And this is where I feel they haven't been as good. It's probably a capacity issue to some extent. And granted I don't always get on their website and access the data, but they don't have the ability to put together comprehensive reports on their monitoring all the time and I don't think they do that every year, but as funders you would usually expect that. But we know them and we know what they're up against and able to do. But that kind of communication is needed – this is what we can do and can't.

[10] A few entities included said that they provided funding to BEMP only or primarily on the grounds of the educational value that BEMP provides, but said they also use BEMP data because it was helpful and available. At the other end of the spectrum are entities that contracted with BEMP as if the educational component didn't exist, solely for monitoring information. Some others included in this study accessed BEMP's dataset, but had no financial connection to the program.

The kind of increased communication that interviewees said would be useful varied and does not appear to have a relationship to any financial tie to BEMP (i.e. in contrast to the above quote, some funders do not expect any additional analysis from BEMP in exchange for funding, and some interviewees from entities that do not contract with BEMP said they would like to request more presentations). Some interviewees said that they need only to be reminded more often of key findings, while others said nothing less than a face-to-face meeting with BEMP staff would increase their understanding of findings. Decision makers reported that, when faced with a pressing decision, they struggle to remember relevant findings from past BEMP reports or presentations. One manager explained this position, and why she was hesitant to share her view with BEMP:

> If we only hear it once, we can definitely forget it. But how can you put that on BEMP? They're busy. But at the same time, how do you keep getting reminded to use this info when getting ready to go after a project?

A number of interviewees said that they were more likely to remember the relevant findings from BEMP if they had learned of them at a presentation than from reading it in reports, but said they might forget about important findings later either way. As one scientist put this, "When they do a presentation everyone says 'that's great' and 'we'll remember that in six months when we make a plan.'…but [we] don't." A manager explained how the different formats could be helpful at different times:

> I'd love to see them do more presentations… In my day-to-day job, I get lost in the details when [I'm] doing an evaluation, [but I] can say, 'Oh, let's go look at the BEMP data.' If they are doing presentations, it helps you keep it forefront in your head.

Interviewees from eight of the 13 bosque-managing entities said they communicate directly with BEMP staff to request data, get help with understanding the data, or to request additional support. Those that were not in direct communication with BEMP said this was either because they didn't use BEMP data, or didn't know that BEMP would be available for help.

The interviewees who reported the closest level of communication with BEMP were also those using monitoring data for decisions most consistently, whether they had a decision-making protocol or not. These entities were also the ones to report that BEMP had initiated communication with them about a management issue or decision. A manager told of when BEMP noticed a variation in the record at a site for one entity:

> [BEMP told] us, "hey, we found these insects here that we're not seeing them other places." And that's a red flag for us to say, "Something's happening here that we might need to keep doing."… They did [contact me about it]! They said, "hey, this looked a little different and we're not seeing these anywhere else." So maybe we should look more into it.

Other interviewees said they would like to see this same level of initiative from BEMP, as this scientist requested:

> Maybe they could work with my agency to set up some separate meetings with the agencies that could use the data to make clear how they could use the data. It has been incumbent on me to contact them but they can do the same thing and come to me. [BEMP could] identify those people and say "how do we get involved?" because that's what makes our lives fun.

Interviewees had suggestions not only for how BEMP might advise decision makers on how to use their data, but many suggested that BEMP could take a stronger position in guiding habitat restoration planning. A scientist put it this way:

> I'm not sure BEMP is going to their constituents [and saying], "here's the data and it indicates your project worked really well or it didn't." They are just overwhelmed with collecting all of the data.

Another manager was not alone when he clarified that providing more information about the ecological outcomes of management actions was desirable, but for BEMP to attempt to evaluate management approaches was not. This was an important distinction made by interviewees and summarized well by this manager:

> I think that's why they have any power is because they don't do that [evaluate management approaches]. The rest of us are tied up doing that all the time; that is all the literature is. I think for them to do that would be a mistake, especially to be so away from all the policy and politics. [But instead] to say, "Last year you had 10 cottonwoods, this year you have none." Without saying, "The stuff you are doing to manage your cottonwoods sucks." It's a different type of statement so they have the ability to talk about the system as a scientific study rather than as a management issue.

5.3.3. Future management objectives will require a comprehensive monitoring plan

Interviewees representing 16 of the 18 entities said that they feel the future of data-informed decisions in this region requires a reach-wide and collaborative approach to monitoring. Interviewees said that future monitoring should be able to: address data gaps; create or continue to generate information that is useful for future managers; evaluate restoration methods; include and support BEMP; share information that reduces uncertainty for current managers.

One manager summarized what many interviewees said was most challenging about the current approach to monitoring and bosque management:

> We need to look at our – really what are our – critical monitoring needs in the Middle Rio Grande…[A scientist] has tried really hard to compile a lot of data and get them into databases and they [people at a particular agency]

> have funded a lot of maps and it's helped form a better picture of collaborative management. There's a monitoring plan that's being produced for the endangered species program, but we need a larger monitoring strategy for the whole Middle Rio Grande to understand where the data gap is, because projects tend to be compartmentalized. [We] can't have a [BEMP] site everywhere you have a project.

Interviewees who identified this need for a collaborative and comprehensive approach to monitoring in the reach often said this was beyond the scope or ability for any one entity to direct. The quote above demonstrates this manager's view that the Collaborative Program does not have a wide enough perspective to lead such an initiative. A number of interviewees said that they were disappointed that the Collaborative Program "hasn't put together a monitoring program for either sites or species." Interviewees said that the Collaborative Program has been more focused on the endangered species than on the habitat, contributing to the deficit of general ecosystem monitoring data. BEMP was suggested as a potential leader for a monitoring planning process, as was another science-based program that does not manage land. One manager described the potential for BEMP's leadership role in developing a comprehensive monitoring approach this way:

> [I see BEMP] as the leader of this thing that we're all doing of restoration ecology. They aren't managing land so they have the ability to get us all together and can get us in the room...They don't have a dog in the fight. They

> aren't making determinations on whether the practices we are doing are beneficial or not...I see them as being in the position of leading this conglomerate in the Middle Rio Grande.

Another manager emphasized the value of BEMP's scientific perspective in the development of a management-oriented monitoring plan. She said that what was missing was a mechanism for,

> Bringing people together around where are we with monitoring and what are our needs. We know we need basic ecological monitoring and that's what BEMP is doing and that's good. But what else are the data gaps for managers? They should be driving that bus. And getting those folks all together with the scientists – they [the scientists] might see other questions, too.

One policymaker emphasized the need for a holistic view of managing in the Middle Rio Grande bosque, saying that "getting a single view of the area" through comprehensive tools based on monitoring and mapping was "something BEMP could take a key role in." Another policymaker described the qualities that a monitoring program should demonstrate: "What I think monitoring ought to be is like standardized, collaborative, transparent, and accessible, but I don't have experience with something that had those four [characteristics]." The interviewee added that,

> Monitoring by itself doesn't work to do that… We're missing something that creates connection between good monitoring and good process. We're missing the step where we look at the numbers before we go into the next project**.**

This policymaker, and 15 other interviewees, recommended a more coordinated approach to monitoring for management in the Middle Rio Grande. For generating reach-wide standards, one scientist said that she would like to use BEMP data to "develop some protocols based on their groundwater data." Another manager likewise suggested shared monitoring protocols:

> If the group [of bosque managers] decided what their monitoring protocol was, if we were in agreement as a body that goes out for watershed-wide funding – like this [set of monitoring data] is what we're interested in… this is what we're trying to achieve through our monitoring – if we had some agreement about this [what is important to monitor]… it would be easy for it to be in our scope of work.

While some felt that BEMP could risk seeming politicized by being more involved in discussions of management, others said that such involvement would help BEMP continue to become more relevant to its land-managing funders. While appreciating the "fine line they have to walk," interviewees widely acknowledged that, because BEMP holds a respected scientific position and a reserve of relevant

information, any comprehensive monitoring plan would benefit from their close involvement, if not their leadership.

5.3.4. A culture of using monitoring information to make decisions will improve management outcomes

Seventeen interviewees from 17 entities said that a culture supportive of science-based and monitoring-informed decisions is needed in Middle Rio Grande bosque management. The need to create a culture of using monitoring data was related to making better use of BEMP's ecological information, but is mostly driven by larger-scale concerns. One policymaker described this as a smart strategy in the face of other pressures on managers to defend their decisions. He described current monitoring in upland systems as inadequately tracking the ecological consequences of restoration treatments while the incentives to restore forest health transfer from grant-based initiatives to market-driven industry. He predicted, "if we don't create a culture around doing this, then the industry will pick up and we won't know what we've done." While bosque restoration is probably not as likely to generate this same tension (because the products are generally less tangible – e.g. habitat quality, species diversity), others expressed this concern, too. Another policymaker suggested that BEMP and similar monitoring programs should prioritize publishing their findings so it "winds its way back in" to resource management discussions. Some of the entities represented in this study have policies that require or otherwise normalize science-based decisions. Interviewees referenced policies and requirements like these as contributing to their culture of data-use, but even these said that they "would like to do better with that."

Saying that BEMP's annual data users' meeting had not yet created an imperative that one consults monitoring data, one manager observed that normalizing data-informed decisions requires not only sharing the results of monitoring and research, but managers must also discuss how they can apply the result to their work. Again acknowledging the challenge for scientists at the intersection of research and policy, he clarified:

> BEMP can help with creating a culture for having access to the monitoring data and that you do something with the data. That's different than scientists acting as advocates for certain management approaches. So it's about BEMP creating a platform and guiding the game, because we all have to do that with the structures of our own institutions.

6. CONCLUSIONS

6.1. Discussion

Whereas other studies have focused on citizen science as a catalyst for education or scientific research, this study investigates the role of citizen science in environmental management. The Middle Rio Grande bosque is a suitably complex social-ecological system for such a study, being host to both management uncertainty and a well-established citizen science program. By focusing on decisions and decision makers, I intended to study the transformation of environmental knowledge into action. I chose to analyze qualitative data from interviews with decision makers from governmental entities that have a stake in Middle Rio Grande

bosque management in order to explain the role of ecological monitoring data, especially from citizen science monitoring, in informing bosque management decisions. I found that the citizen science data generated by BEMP contributes to the decision routines of bosque governance, but that the data may not lead to improved quality of decisions. In the remainder of this discussion, I compare the results of this study to those in the literature and explain the findings where the literature is inadequate. I provide seven recommendations for improving the application of monitoring data for bosque decisions, directed to BEMP, to bosque decision makers, or to both groups together, and discuss the relevance of a decision-making tool from adaptive management in particular.

Johnson's (2012) definition of ecological monitoring specifically distinguishes monitoring from measurements taken to establish baselines or evaluate projects for either implementation or effectiveness. After interviews revealed that the majority of 'monitoring' other than that generated by BEMP would not fit this definition, I considered whether to broaden the definition. I evaluated how interviewees spoke about 'monitoring' and 'data' and concluded that Johnson's definition remains appropriate, even if the terms are sometimes conflated. Responses provided strong evidence that interviewees see project-specific monitoring data as data without a learning-related purpose and not designed to be applied beyond that project. In contrast, BEMP and some other monitoring projects that interviewees discussed are ecological monitoring studies; the value of the programs is not tied to any specific site and it is designed to generate new knowledge. I find this to be an important distinction because ecological monitoring

came to the fore in resource management scholarship out of the recognition that a 'whole-problem' method of analysis is necessary to detect many important aspects of ecosystem condition; further, data collection for project design and compliance informs ecological knowledge by accident rather than intention. However, while well-designed ecological monitoring studies maximize resources, it would be possible to consolidate data such as project-specific monitoring data for exploratory analysis that might reveal useful insights, if entities share this data.

Facing shortfalls in the resources needed to generate monitoring data of their own, decision makers look to BEMP for data. If information is available that can be readily applied to bosque management decisions, participants said they prefer to inform themselves with ecological data. In the absence of immediately useful information (i.e., without data that has been analyzed according to a relevant management question), decision makers may review raw data and draw their own conclusions, or determine they cannot use that data. As the only source of long-term ecological monitoring data for the Middle Rio Grande bosque, BEMP data influences the decision routines of decision makers who feel they should inform their decisions with some form of ecological data. If BEMP were to stop generating citizen science data and research, significant decision makers would be impacted in how they arrive at decisions for the Middle Rio Grande bosque.

Interviewees said that they make 'better' decisions when they inform themselves with monitoring data. Study results indicate that, by 'better' interviewees meant justified (i.e., substantiated by credible information) and result in actions that influence the system toward the desired condition or management

objective. For some, improved decisions could additionally mean the decision was politically acceptable. Most interviewees indicated that science should be the fundamental basis for their management decisions, but that sometimes it is not. The participants in this study were tasked with managing land and water resources that are often highly regulated; managers face consequences when their decisions cause harm or undue expense. Interviewees expressed that they want to do their jobs well and that monitoring data, especially BEMP data, help direct management actions toward desired outcomes. Decision makers made clear they are interested in reducing uncertainty about what actions will support a healthy bosque ecosystem. However, this study did find that some bosque decision makers do not use data to inform their decisions even when data is available; availability of useful information is not the only determining factor of decision routines. According to interviewees, their decisions were prescribed by the specifics of institutional agreements in the Middle Rio Grande. Institutional agreements include, for example, the contracts between BEMP and bosque management agencies, as well as requirements for project-specific data collection that generate vast amounts of data, but are difficult to consolidate and analyze in a way that contributes new insights.

Although many interviewees acknowledged that requirements to use data would make it more likely that they would have the data needed for decisions and it would be easier to apply that information, I interpret their prompt pivot (away from creating a requirement, toward reliance on a culture supportive of decisions that are informed by monitoring data) as avoidance of 'hard' rules. It was this articulation that resulted in identifying "lack of any requirement to use data" as a barrier, rather

than naming "a requirement is needed" as a potential decision aid. Some interviewees clearly do support requirements to use data, but they also often admitted that they would rather not have to abide by them. As the above analysis demonstrates, professional discretion is what allows decision makers to influence policy. For these reasons, one important finding of this study is that Middle Rio Grande bosque decision makers prefer 'soft' rules to guide their decisions to be more informed by data.

An important and surprising finding of this study is that a majority of interviewees said that they were unsure whether they knew when data was necessary to be able to make a given decision. To address this uncertainty, clear decision-making protocols can be adopted by an entity (or even by an individual) that classify decisions or decision 'types' according to whether data is necessary. As described in the Results Section, instituting a decision-making protocol meant some interviewees could base more decisions on data. A few interviewees who use adaptive management as a decision-making protocol did, however, express uncertainty about determining when data is necessary for a given decision. This suggests that an adaptive management framework may be more helpful for clarifying general decision routines than particular decisions.

Interviewee responses reveal confusion about the policy role that BEMP intends to play in relation to bosque management. BEMP maintains in its mission statement, included in all publications, that it seeks to inform public policy.[11] Yet,

[11] BEMP's mission is, "Science, education, and stewardship of the Rio Grande and its watershed through long-term, hands-on student research of ecosystem response and function to inform public policy."

when asked how BEMP could best inform policy, some interviewees disputed that BEMP has any place in determining or informing policy. Interviewees emphasized BEMP as neutral regarding policy, able to avoid seeming politicized, and primarily an educational program. A few interviewees proscribed any attempt by BEMP to influence policy, and used language that suggests that the power to determine BEMP's role in policy might lie with entities other than BEMP. To other interviewees, the topic seemed like a new idea. One scientist said that BEMP had "probably informed policy, but they haven't been a policy driver," suggesting that BEMP's influence on policy was unintended. This level of misunderstanding about BEMP's role in informing policy is especially important for understanding BEMP as a citizen science ecological monitoring program since ambiguity about the purpose of monitoring has been connected with program failure (Nichols and Williams, 2006; Lindenmayer and Likens, 2009; Hochachka et al. 2012).

In a parallel debate about BEMP's role in guiding bosque management, some interviewees said they would like to have more management recommendations and/or evaluation from BEMP staff scientists, while others objected to this possibility. Similar to the divergence of opinion about BEMP's policy role, interviewees who objected to BEMP evaluating management actions seem to be unaware that such evaluation of management outcomes was one of the main stated purposes for the creation of BEMP. The position, articulated by some interviewees, that 'unbiased science' and 'on-the-ground management' should occupy separate realms of the bosque management process indicates a wide distance to be crossed for collaboration between researchers and managers. As BEMP attempts to remain

essential to bosque decision makers in light of potential funding shortages, it may benefit from working with its stakeholders to better define its role relative to public policy and management evaluation. Interviewees were divided on both issues, making it difficult to make a recommendation for how BEMP should adapt to the expectations of its stakeholders.

BEMP follows an ecological survey design for its long-term research that defines it as surveillance monitoring as described above in Section 2.2. Because surveillance monitoring necessitates the demanding analyses of pattern discovery, BEMP produces information (via data analysis) at a rate that is not determined by (and can be slower than) the rate of management decisions. As some researchers predicted of studies that are not hypothesis-driven, (Lindenmayer and Likens, 2009; Nichols and Williams, 2006) BEMP's data analysis is having trouble keeping pace with management needs. If BEMP's information is to become more useful for improving bosque management decisions, BEMP will need to produce reports in a timely manner and its data analysis will need to focus on generating information that is directly applicable to management questions. BEMP should be willing to adapt its protocols to the extent possible without compromising the value of its long-term data record, and could look to adaptive monitoring (Lindenmayer and Likens, 2009) for help. It would be impossible to expect BEMP to provide all of the long-term monitoring data and analysis necessary to address management concerns and reduce management-related uncertainties for the Middle Rio Grande bosque.

There is evidence that a lack of integration between long-term ecological monitoring and stand-alone question-driven research is limiting the availability of

information for decision makers. BEMP currently conducts shorter-term hypothesis-testing research with students on topics relevant to management (for example, occupancy rates of wildlife such as porcupine). Integrating the results from these research projects into the analyses of current long-term ecological monitoring may help translate more of BEMP's information into improved bosque management.

BEMP is far from alone in its struggle to report new findings. It is a common problem for long-term ecological researchers generating large data sets to not give enough attention to synthesis, summary, and analysis. For example, the National Science Foundation's Long Term Ecological Research project has acknowledged the challenges of managing/curating information while continuing data collection, especially with a policy of open data sharing (Karasti and Baker, 2008).

The lack of literature about citizen science monitoring data applied to resource management suggested that there might be something about citizen science monitoring data that limits its applicability to resource management. Interviewees in this study firmly denied that this was the case. BEMP exists as a case study of citizen science successfully influencing positive environmental changes in the local ecosystem that it monitors, and this research helps to address the gap in the literature identified by Conrad and Hilchey (2010) regarding successful use of community-based monitoring data by decision makers.

6.2. Recommendations

The Middle Rio Grande region's population is projected to grow by 50 percent by 2040 (Metropolitan Transportation Board, 2015). Beginning with the 1993 Bosque Management Plan, the institutional arrangements pursuing bosque

health and sustainability have not explicitly incorporated the pressures of human demands (i.e., housing and recreation) on the bosque ecosystem, and little of the available ecological data has been analyzed in terms of human impact. A conceptual model for the system that acknowledges humans as integral components of the ecosystem (Bartuska, 1999) would help to better identify important scales, processes, structures, and feedbacks. It appears that no unified conceptual model for the Middle Rio Grande bosque ecosystem now exists. A conceptual model is a critical tool for adaptive management, or for any approach to sustainable land use planning, because it describes what is known about the whole system and its dynamics. Coupled with monitoring data, a conceptual model can be used to build predictive models for simulating potential future variability, especially important in situations where "delayed detection of trend estimates can lead to substantive loss of ecological integrity or high restoration costs" (Garman et al., 2012: 246).

There was broad agreement among participants in this study that data gaps need to be identified for the Middle Rio Grande bosque. Such a task would benefit from a specified strategy and predetermined application to be manageable and to garner necessary resources. A list of attributes of relevance for assessing the health of the bosque (*sensu* Pocock et al., 2015), accomplished through partnership between BEMP, bosque management entities, and interest groups, would be a reasonable starting point for a collaborative and reach-wide monitoring strategy, called for by 15 of the 18 interviewees in this study. Reach-wide data exists and, although there are gaps, it could now be analyzed in ways that contribute to a reach-wide strategy.

Spatial analysis tools would provide an organized means for gathering the evolving set of information, while also supplying a necessary and effective form of communicating large amounts of data. The Forest and Watershed Health Institute (FWHI) at New Mexico Highlands University has initiated a database and mapping project that will cover the entire Rio Grande river corridor and FWHI intends to include BEMP data. BEMP could play an important local role for the Middle Rio Grande by educating their community of bosque decision makers, students, and educators about the relevance of maps for bosque stewardship and research.

Based on interview responses and the reviewed literature, I offer the following recommendations directed primarily to BEMP and Middle Rio Grande bosque decision makers, but also public interest groups.

1. *Analyses* from BEMP that are more frequently presented and responsive to management concerns may increase *financial support* to BEMP from organizations that stand to benefit;
2. BEMP should promote awareness about the *many citizen science* initiatives, which are engaging the broader public in data collection. Bosque management entities should encourage *targeted monitoring and question-driven research* by providing funding to capable programs. BEMP should link to all citizen science information available on its website;
3. BEMP, FWRI, and bosque management entities should host events and create an *online platform for the identification of data gaps* and use *spatial analysis tools* to update and communicate these broadly. Participants should ask "Why?" the missing data would be useful to avoid wasting resources;

4. BEMP and/or a well-funded bosque management entity should operate a monitoring *database* that all entities with bosque management jurisdiction may access and contribute to;
5. Entities with bosque management jurisdiction should rotationally host an annual *monitoring roundtable*, where BEMP and others present relevant findings and managers focus on learning;
6. BEMP should lead bosque decision makers and engaged community members in the creation of a reach-wide and comprehensive *monitoring plan*;
7. BEMP and bosque decision makers should secure the *long-term resources* to adopt an *adaptive governance framework* for reach-wide, collaborative bosque management planning. Include decision-making '*triggers*.'

6.3. Relevance and application of "triggers"

Nie and Schultz (2012) examine the political and legal context of adaptive management and demonstrate the need for pre-identified commitments, or decision-making "triggers." Their argument is that adaptive management introduces greater flexibility and discretion to land management agencies, which can be misapplied or abused. Adaptive management can be implemented in ways that make it more difficult to hold agencies accountable for management outcomes. The terminology of adaptive management plans can be vague, which leads to risk of failure to survive judicial review. Adaptive management plans, and other management plans that attempt to take action amidst uncertainty, are subject to applicable environmental laws and regulations. Triggers are a precautionary

mechanism; a trigger point "specifies what actions will be taken by an agency if monitoring information shows x or y…as predetermined decisions, or more general courses of action, [that] are built into the adaptive framework from the beginning of the process" (Nie and Schultz, 2012).

There are multiple opportunities for applying triggers to Middle Rio Grande bosque management. Ecological thresholds can be used as management thresholds (Martin et al., 2009) wherein a pre-set limit to the magnitude or extent of human disturbance that is permitted, and after which unacceptable ecological change is expected (Johnson, 2013). Future bosque land planning and governance processes should include parties interested in human activities such as recreation and residential development in the bosque, in order to work with (rather than around) these sources of human disturbance. Triggers would help determine the governance response to reaching a regulatory limit of human activity in the bosque.

Management triggers may provide a venue for BEMP to address management questions. Working together with BEMP, bosque managers might articulate standards for bosque condition that are measurable according to BEMP's protocol, or with minimal additions or adjustments to the protocol. This kind of agreement would satisfy the divergence of opinion expressed by interviewees about how BEMP should relate to evaluating management outcomes. BEMP analysis would be in reference to the known thresholds, and therefore would be question-driven (i.e. Are indicators moving away from or toward ecological thresholds, or staying the same?). Decision makers might find they are more motivated to practice their discretion to

use monitoring data because it is directly relevant to their management objectives and alleviates some level of legal vulnerability.

I also propose applying triggers retroactively, as a tool for evaluating either particular restoration methods (e.g., Do installed backwaters effectively recruit willow?) or general, broad methods (e.g., Does nonnative vegetation removal lead to increased native species diversity?). In this application, a pre-determined goal for a set timeframe (i.e., three or five years in the future) would be set for some aspect of bosque condition that can be assessed using ecological monitoring data, ideally BEMP data. When the end of the timeframe is neigh, the previously agreed upon method of analysis would be done for the appropriate area, and this analysis would reveal (spatially) where the goal was met, where it was just missed, and where the trigger is pulled that stops or alters that restoration method.

Triggers, like adaptive management, are no panacea (Allen and Gunderson, 2011). Nie and Schultz (2012) make a number of recommendations for the use of triggers meant to address some of the challenges of "learning while doing," which are: include a clear feedback loop for learning such as specifications about what will be done with monitoring information (i.e., clarify decision routines); identify pre-specified monitoring and mitigation requirements; set a continuum of trigger points instead of a single red-light trigger that must not be crossed; and maintain a multi-party monitoring oversight board to ensure transparency and accountability. Ultimately, we all know that learning can be difficult. Allen and Gunderson (2010) identify pathologies that may be present in resource management, with a focus on

adaptive management, and some of these could be said to be already present in the institutional landscape of Middle Rio Grande bosque management.[12]

6.4. Implications, limitations, and further research

This research was limited predominately by time. Even as I restricted my investigation to the use of monitoring data (significantly excluding from my investigation the generation and transmission of monitoring data), the complexities that surround the use of data for decisions were great enough to hinder the research process. Much of the qualitative data used here was potentially laden with hidden or multiple meanings. Interviewees were often drawing on a decade or more of personal experience working to resolve management challenges in the Middle Rio Grande bosque, and some interviewees made veiled references that I could not always clarify or use as the basis of my conclusions. My own lack of personal experience with the Collaborative Program proved to be a challenge for understanding references to that dominating force in bosque governance.

Because this study focused on bosque management decisions and decision making, BEMP's perspective, while closely related, was not included. This exclusion was important to the study design insofar as it allowed me to avoid inserting my own bias, which might occur while contrasting descriptions from BEMP and decision makers. I also wanted to reduce the perception among interviewees that I

[12] The pathologies identified by Allen and Gunderson (2010) include: 1) lack of stakeholder engagement; 2) experiments are difficult; 3) surprises are suppressed; 4) prescriptions are followed ("processes that are too complex in their internal organization and too complex and fragile in their stakeholder network are apt to stick to the prescription no matter what."); 5) action procrastination (learning and discussion remain the only ingredients); 6) learning is not used to modify policy and management; 7) Avoiding hard truths (decision makers are risk averse); 8) the process lacks leadership and direction; 9) focus on planning, not action.

was simply advocating for BEMP. Another concern was perceptions of confidentiality: I did not want to be in the position of being asked by any interviewee about information that other parties would not want me to share. It became evident that this likely would not have been a problem since all interviewees were respectful of the confidentiality of others' observations. While excluding interviews with BEMP staff was necessary, I did attempt to find relevant information that would confirm or refute the statements of interviewees. If multiple interviewees observed or referred to a state of affairs about which I could find no information, I was willing to include that observation in the results.

Additional research is needed to understand how citizen science programs that aim to inform environmental management policy should deal with knowledge generation and transmission. The scope of a master's thesis is too narrow for a comparative study of how and whether citizen science programs generally are supporting natural resource managers to adapt, learn, and respond to environmental change. Programs like BEMP are a force for making dialogue between academic researchers, public resource managers, and policymakers necessary and possible. Study design and communications planning are the foundation of any monitoring program, but should perhaps be seen as adaptable in citizen science so that information becomes more useful over time as the realities change. Partnerships will no doubt be essential for creating and sustaining citizen science that focuses on management decisions.

This study raises some questions that could be explored in future research. Is there a relationship between the use of citizen science data for management

decisions and conservation outcomes? Does the use of citizen science data for land management decisions lead to increased transparency or accountability? When managers feel they have successfully improved the culture of decision making to include monitoring, does this lead to improved management outcomes? Are citizen science programs enhancing the adaptive capacity of natural resource institutions? I am also interested in investigating the potential for opportunistic knowledge generation (such as citizen science) to "speed up" the rate of learning on the part of decision makers and also to pressure institutions to respond more effectively to environmental change.

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8. APPENDIX

Sample Interview Questions

1. What reasons does your agency have for partnering with BEMP? How long has your agency partnered with BEMP or used BEMP data?
2. How does monitoring fit into your agency's management plan/decision-making process/planning?
3. Does your agency use BEMP data? Is BEMP data cited when used in reports?
4. Refer to list of BEMP's data collection. Does your agency use any of this data in management decisions?
5. How do you know whether monitoring data is necessary to be able to make a given decision?
6. Do you know of other entities collecting monitoring data like BEMP?
7. How does your office view the use of citizen science data for decisions?
8. Does BEMP's data influence management policy at your agency?
9. Can you identify any barriers to using BEMP data for decisions?
10. What is the best format for accessing data for your agency?
11. Is doing the data analysis a barrier to using BEMP data?
12. What would make it more likely for your agency to use BEMP data for its management decisions?
13. Is there anything else you would like to share? Who else do you think should be included in this study?