



Collective Action and Invasive Species Governance in Southern Arizona

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ARTICLE INFO

Article history:

Received 2 August 2019

Revised 27 July 2020

Accepted 13 October 2020

ABSTRACT

Invasive plants can have significant negative effects on human and ecological communities, including reduced productivity and biodiversity and increased fire risk. Effective mitigation of invasive species likely requires action by heterogeneous actors who span jurisdictions, sectors, and levels of governance. While there has been significant research to develop targeted mitigation techniques that slow or halt the spread of specific invasive plants, there has been relatively little complementary work to develop knowledge about the implementation of these management techniques through effective governance systems. To address this gap, we interviewed and conducted archival research on land managers involved in the mitigation of buffelgrass (*Pennisetum ciliare*, syn: *Cenchrus ciliaris*) invasion in southern Arizona to investigate how existing and emerging governance arrangements encourage or undermine individual and collective action to manage invasive plants. Our results show that a key challenge of managing invasive species is identifying the mechanisms that will allow heterogeneous actors to overcome internal barriers to coordination with others and enable collective action. These internal barriers are multifaceted, involving laws and policies, cultural traditions and mandates, the availability of monetary and human resources, and information on causes and consequences of species invasion and effective approaches to mitigation. Approaches to solving these problems must include improved knowledge of internal institutional structures and the opportunities and barriers they present to collective action, the preferences of heterogeneous actors when presented with information about future ecosystem conditions absent coordination, the factors that prevent individuals within different organizations from following through on commitments to participate in collective action institutions, and how each of these conditions affects the availability and persistence of resources for mitigation. Together, improved knowledge of the relationships between these factors may provide new approaches to proactive management of emerging resource management challenges, from invasive species to emerging diseases.

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Introduction

Invasion of non-native plants is an emergent environmental problem whose complex characteristics make it difficult for policy makers and land managers to develop durable and effective management solutions (Beever et al. 2019). Invasive plants can have significant negative effects on human and ecological communities, including reduced productivity and increased fire risk (Lyons et al., 2013). However, there is often uncertainty regarding the timing and extent of these impacts, potentially slowing or preventing

the emergence of public support in favor of preventive action and of new management regimes to address the impacts of invasive plants (Brenner & Franklin 2017). Under these circumstances, traditional policy instruments and approaches—such as command and control, market-based, or community-based natural resource governance—may fail to achieve lasting, substantively effective results (Bagavathiannan et al. 2019). While there has been significant research to develop targeted mitigation techniques to slow or halt the spread of specific invasive plants, there has been relatively little complementary work to develop knowledge about the implementation of these management techniques through effective governance systems (Graham et al. 2019). In this paper, we use an in-depth case study approach to understand the collective action challenges presented by invasive species management. We interview land managers involved in the mitigation of buffelgrass (*Pennisetum ciliare*, syn: *Cenchrus ciliaris*) invasion in southern Arizona

* Support for this study was provided by the Office of Research, Discovery, and Innovation and the Bridging Biodiversity and Conservation Science initiative at the University of Arizona and by NSF grant 1924016.

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to investigate how existing and emerging governance arrangements encourage or undermine individual and collective action to manage invasive plants.

Collective action dilemmas occur in situations where individual interests run counter to the common interests of a group of individuals (Olson 1965; Poteete et al. 2010; Baldwin et al. 2018). Where such situations arise, there are potential gains a group can realize if collective action is taken, but individual actors may face insufficient incentives to undertake these actions (Ostrom 1990). Under such circumstances, few private actors will have incentives to provide a good, regardless of the potential gains that could be realized from doing so (Ostrom 2003). Invasive species management is an example of a collective action problem (Graham et al. 2019). Impacts tend to span jurisdictions, sectors, and levels of governance. Effective mitigation of invasive species often requires action by heterogeneous actors who have divergent interests in prevention and mitigation, as well as different resources and capabilities to bring to bear on the problem (Albers et al. 2010; Decker et al. 2012). For example, some invasive grasses provide a valuable forage resource while simultaneously changing fire regimes and reducing biodiversity (Marshall et al. 2011). The actors who are most affected by these changes—recreation users, for example—may not have the resources needed to mitigate the impacts. Meanwhile, actors who are well-positioned to prevent or mitigate harms (e.g., livestock grazers) may see few negative impacts and therefore have little reason to join with others in mitigation efforts. Moreover, emergent problems that are new to a given jurisdiction may require cooperation between and among actors who have limited experience with each other, or there may be institutional and organizational barriers to effective cooperation.

Collective action dilemmas are challenging but not insurmountable. Indeed, a large and growing body of empirical evidence has examined one type of collective action problem—management of common pool resource (CPR) systems—and found that local communities can often manage such problems, provided that appropriate governance arrangements exist to bring resource users together to agree upon appropriate rules for sustainable resource use (Ostrom 1990; Cox et al. 2010; Cox et al. 2016). Recent scholarship on collective action suggests that fundamentally, the resolution of collective action dilemmas requires that relevant actors come together to devise and implement solutions that align individual incentives with those of the group (Baldwin et al. 2018). Presuming that there are gains that the group can realize from effective invasive species management, it should theoretically be possible to devise some sort of governance arrangement—a policy instrument, an informal set of rules, a funding mechanism, a coordinating body—that changes individuals' incentives enough to prompt the actions needed to address invasions. The particular governance arrangements needed, however, will depend on the context at hand, including the nature of the collective action dilemma itself, the characteristics of the actors involved, and the information available about the problem. Scholars have begun to theorize about whether and how Ostrom's work on collective action might be applied to the problem of invasive species management (Bagavathiannan et al. 2019; Graham et al. 2019), but to date there has been limited empirical investigation of invasive species as a collective action problem.

To understand the dynamics of collective action dilemmas in the context of invasive plant management, we focus our attention on a particular case—buffelgrass in the Sonoran Desert of southern Arizona. Invasive buffelgrass poses an imminent and significant threat to the region: if left unaddressed, it can outcompete native species, eventually causing an ecological state change that will fundamentally alter the character and function of the region's ecosystems, increase fire risk, undermine the tourism and outdoor recreation sectors of the southern Arizona economy, and reduce

quality of life for residents in the region (Evans et al. 2001; Friedel et al. 2007; Lyons et al., 2013; Jarnevich et al. 2015; Castellanos et al. 2016). While ecologists and conservation biologists have long warned of the consequences of buffelgrass invasion, and conservationists have developed forums for information sharing and coordination, the diverse public and private land managers on the front lines of buffelgrass management have yet to undertake sufficient individual and collective action to keep the buffelgrass population in check. Specifically, this research shows how existing and emerging institutions for invasive species management promote or undermine collective action between government agencies in the study region. We draw on interview and archival data to explain why past efforts at collective action have failed and to suggest governance mechanisms that might prompt effective individual and collective action by land managers in the region.

Research design, methods, and data

We use the Tucson basin of Pima County, Arizona as a case study (Yin 2018). This region includes a wide range of public and private landowners who have struggled to consistently undertake individual and joint actions that would contribute to the mitigation of buffelgrass impacts. Efforts to promote collective action on buffelgrass occurred as early as 2008, using a range of institutional approaches, and new efforts are continually emerging.¹ The Tucson basin thus provides a useful case to examine how actors have engaged in collective action efforts and derive lessons from the various iterations of management institutions that have formed and dissolved over time.

Our approach is qualitative. We conducted interviews with key informants and conducted archival research on the institutional structure of collective action forums to understand how past and current institutional arrangements promote or discourage collective action for buffelgrass mitigation between land management agencies in southern Arizona. Here, we review our case study site and the methods for interview and archival data analysis.

Study Site

Buffelgrass is a warm-season bunchgrass native to Africa (Marshall et al. 2011). It was introduced to southern Arizona, Texas, northern Mexico, and other regions around the world for its drought tolerance and its ability to withstand moderate to heavy grazing by cattle and other livestock (Van Devender & Dimmitt 2006). With these benefits also come challenges. Buffelgrass is a fire-tolerant species native to African savannah ecosystems, while many of the places where it has been introduced are fire-intolerant desert scrub ecosystems. This is certainly true for the case study region (McDonald & McPhearson 2011).

The Tucson basin is located in southern Arizona (Fig. 1). Southern Arizona is characterized by a varied topography that promotes high plant and animal biodiversity (Philips and Comus 2000). Tucson, Arizona is the only major urban center in the region. It is located in a desert valley at the base of three mountain ranges: the Santa Catalina Mountains, the Rincon Mountains, and the Tucson Mountains. The valley floor and lower slopes of these mountains up to about 1 200 m are characterized by a desert scrub plant community (Lowe 1964; Philips and Comus 2000). This plant community consists of cacti, small desert trees such as palo verde and ironwood, woody shrubs, and sparsely distributed grasses (Philips and Comus 2000). Native desert scrub is highly fire resistant—wildfires are generally unable to spread due to poor connectivity between plants. At the same time, this characteristic makes the

¹ One of this study's coauthors has been involved in several of these efforts.

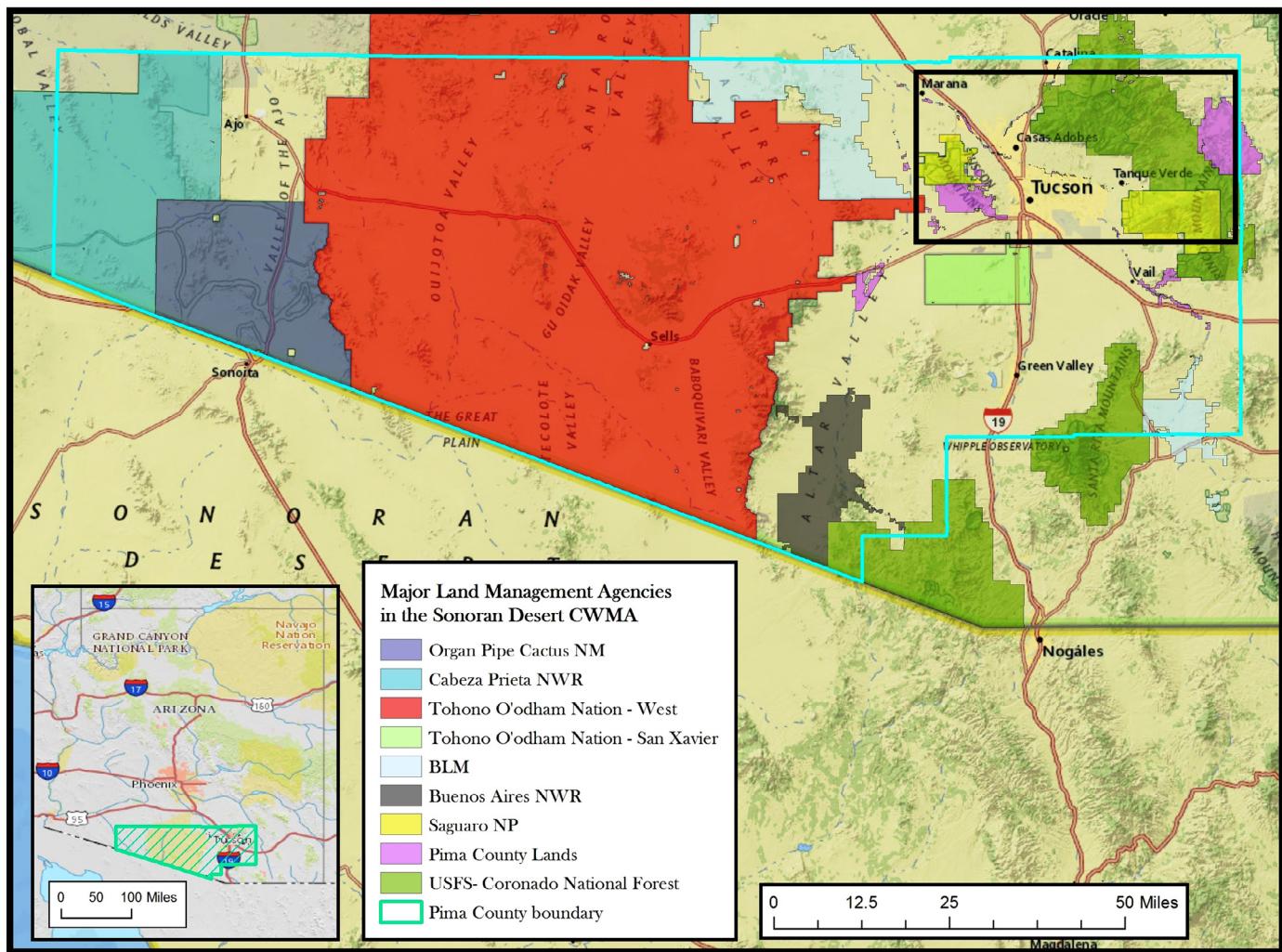


Fig. 1. Map of study region. The complex mix of jurisdictions in the region includes USFS, NPS, Pima County park lands, City of Tucson, Native Nations, and other jurisdictions. The green outline is the boundary of the Sonoran Desert Cooperative Weed Management Area. The smaller black box is the approximate scope of the study area for this research. Buffelgrass occurs in places throughout the Sonoran Desert CWMA, but the heaviest invasion is centered around Tucson, Arizona. Source: Sonoran Desert Cooperative Weed Management Area/Arizona Sonora Desert Museum.

plant community highly vulnerable to degradation by fire when it does occur because the plant species present are not adapted to fire. Wildfires are not a common form of disturbance in the system (McDonald & McPhearson 2011). The iconic saguaro cactus, which suffers high mortality when burned, is also endemic to the Sonoran Desert and is the primary reason for the designation of Saguaro National Park (NPS 2019a). The saguaro cactus is of critical importance culturally, economically, and ecologically in southern Arizona.

Buffelgrass has two major impacts on the ecosystem, both of which can result in large-scale ecosystem degradation. First, it outcompetes native flora for scarce water and other resources (Stevens & Fehmi 2011; Lyons et al. 2013; Castellanos et al. 2016). Buffelgrass typically responds more quickly to rainfall than native grasses and requires less rainfall to initiate growth at the beginning of the growing season. Southern Arizona experiences a bimodal rainfall regime with about half of the precipitation arriving in the form of intense thunderstorms in the summer and the other half arriving during the winter months (Philips and Comus 2000). Unlike many native warm-season grasses, buffelgrass will grow and reproduce in both the summer and winter rainy seasons when rainfall and temperatures are adequate. These characteristics allow it to outcompete most native flora and develop near monocultures over

large swaths of previously highly biodiverse desert scrub (Olsson et al. 2012).

Second, buffelgrass is adapted to fire. Most of the year, buffelgrass is dormant and highly flammable. This characteristic, when combined with its ability to grow in dense patches that fill in the empty spaces between native vegetation, allows buffelgrass to carry fire across what would otherwise be a fire-resistant landscape (McDonald & McPhearson 2011). While a large fire has not occurred in the study region since the introduction of buffelgrass, many experts see such an event as inevitable if buffelgrass is allowed to persist and spread (Friedel et al. 2007). The introduction of landscape-scale fire is expected to cause an ecological transition from a biodiverse desert scrub plant community to a buffelgrass-dominated desert savannah, including significant reductions in biodiversity and near-complete loss of saguaro cactus (McDonald & McPhearson 2011).

The invasion of buffelgrass in the Tucson basin takes place within a complex institutional and policy context. Land owners and managers in the region include federal agencies, the National Parks Service (NPS) and the US Forest Service (USFS); Pima County and various county departments (e.g., Parks and Natural Resources, Transportation, and Flood Control); the City of Tucson and its various departments; private individuals; and homeowners associa-

Table 1

Specific actors involved in buffelgrass management in Pima County, Arizona. Actors are separated into three groups: policy actors, who implement land management laws and policies at various levels of government and have direct land management responsibilities; economic actors, who do not have administrative authority to implement laws and policies but must follow existing federal, state, and local laws and have an economic interest in outcomes of buffelgrass mitigation; and community actors, who seek to influence laws and policies related to buffelgrass mitigation and may participate in management but are not directly responsible for implementation of law and policy.

<i>Policy Actors—own land and set land management policies:</i>
National Parks Service
Bureau of Land Management
US Fish and Wildlife Service
US Forest Service
Department of Defense
Tohono O'odham Nation
Pascua Yaqui Tribe
AZ State Lands Department
AZ State Parks
AZ Dept. of Transportation
Pima County
City and County Parks Depts.
Pima County Dept. of Transportation
Cities and towns regionally
<i>Economic actors—own land but do not directly set land management policies:</i>
Homeowners' associations
Land developers
General public
<i>Community actors— influence land management policies but do not implement them:</i>
Nongovernmental organizations

tions (HOAs) (Table 1). In some cases, these actors are wholly independent of others. For example, the NPS and USFS operate according to federal laws, rules, and policies, and Pima County and the City of Tucson have no explicit power to regulate or directly influence management decisions on federally owned lands. Similarly, the NPS and USFS have no power to regulate adjacent county or privately owned lands. In both of these examples, however, decisions made by the managers on neighboring properties can affect the likelihood of buffelgrass's continued spread across the landscape. The USFS, NPS, and Pima County are the three largest landowners in the region and the largest landowners of wildlands affected by buffelgrass invasion. Because of this, these three actors are the most important for successful collective action to mitigate buffelgrass impacts. We focus our interviews on these three actors.

Basic Attributes and Biophysical Conditions of Actors

Saguaro National Park (SNP)—The NPS was established by Congress in 1916 with a mission to “conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations” (NPS 2019b, p. 10). This mission sets the NPS apart from other US federal land management agencies in that the NPS is tasked with maintaining natural areas as they are for future generations rather than enabling sustained use of land and resources by a range of users. The NPS's resource conservation mission is reflected in the legislation establishing each national park, including SNP, initially designated as a national monument by presidential proclamation in 1933, with explicit reference to the extraordinary natural values present in the areas included in the monument and their need for preservation. The proclamation calls for protection of “giant cactus” (NPS 2019a) because of its “outstanding scientific interest” (NPS 2019a). The national monument was created out of lands belonging to the USFS Coronado National Forest; the proclamation makes specific reference to the differences in management mandated for monument lands relative to the prevailing management of the national forest: “any use of

the land which interferes with the preservation or protection as a national monument is hereby forbidden” (NPS 2019a).

Over time, the monument was expanded to include large land holdings both east and west of the city of Tucson, Arizona (see Fig. 1). The monument was officially converted to a national park by Congress in 1994, at which time the most recent expansion of the park took place. Today, the total area of the park is ≈37 000 ha. The eastern portion of the park is over twice the size of the western unit. The overall mission of the park, to maintain the unique resource values, specifically saguaro cactus, was not changed. The eastern and western portions of the park vary significantly in geography and ecosystems present. The eastern unit of the park is larger and more geographically and ecologically diverse, with elevations ranging from 750 m to over 2 500 m (NPS 2019c). Saguaro cactus and buffelgrass are only found on the lower slopes of the Rincon Mountains up to ≈1 300 m (Philips & Comus 2000). The western unit of the park ranges in elevation from 700 m to ≈1 300 m (NPS 2019c). As a result, saguaro cactus and buffelgrass are capable of growing virtually anywhere in this park unit. Between both park units, SNP receives approximately one million visitors per year and is a significant contributor to Tucson's economy.

Coronado National Forest—The overall mission of the USFS is quite different from that of the NPS. The USFS mission is stated in policy in the agency's Organic Act of 1897, “... for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States” (USFS 2019a). This mission was affirmed in the Multiple Use Sustained Yield Act (1960) and the National Forest Management Act (1976), both of which establish rules the USFS must follow in timber, range, and general resource management. Beyond specific legal mandates, the USFS also has a strong cultural tradition of multiple use management that can be traced back to the first chief for the USFS, Gifford Pinchot. Pinchot espoused a conservation ethic grounded in a utilitarian view of sustainability, “... the greatest good for the greatest number in the long run” (USFS 2019b), that has held such sway in the culture of the agency throughout its history that its official centennial film and book are titled *The Greatest Good* (Miller & Staebler 1999).

The ≈695 000-ha Coronado National Forest is one of the most diverse national forests in the United States due to its unique configuration. Unlike most national forests, the Coronado is not one contiguous block of land. Instead, it is made up of disconnected islands of forest found on successive north-south trending mountain ranges across southern Arizona (see Fig. 1). These mountain ranges are administratively organized into five ranger districts, with each ranger district typically responsible for one or two mountain ranges. The forest boundary for each district is typically on the lower slopes of a given mountain range. This results in the presence of ecosystems ranging from desert scrub to subalpine forests on the highest peaks. Elevations range from ≈700 m to 3 000 m (USFS 2019c). Like SNP, buffelgrass is found at lower elevations on mountain slopes surrounding the Tucson metropolitan area coincident with saguaro cactus. Unlike SNP, many districts of the Coronado have no or very little buffelgrass. Most of the suitable habitat for buffelgrass in its current range is found in one forest district, the ≈105 000-ha Santa Catalina District, which borders Tucson.

Pima County Natural Resources, Parks and Recreation—The parks department in Pima County, Arizona is unique. In addition to owning and operating urban parks throughout the county, Pima County also owns thousands of hectares of natural areas and ranchland. The natural areas are managed similarly to national parks—for conservation and preservation of natural resources for the enjoyment and education of the public. Ranchlands were purchased throughout the county to maintain rural character, prevent urban sprawl, provide habitat for wildlife, and support the regionally important

cultural heritage of ranching. The natural areas program, which includes the natural areas and ranchlands, developed over time through the adoption of taxpayer funded bonds to purchase land and through the implementation of an agreement with the federal government for the protection of threatened and endangered species (Pima County 2019a).

While buffelgrass is found on county-owned lands throughout the Tucson metropolitan region, Tucson Mountain Park is the center of both buffelgrass invasion and mitigation efforts by the county. Tucson Mountain Park is an $\approx 8\ 000$ -ha natural area west of Tucson. It shares a boundary with the western unit of SNP and covers the southern portion of the Tucson Mountains. Between SNP and Tucson Mountain Park, the vast majority of the Tucson Mountains have protected status. The topography and plant communities are also shared with SNP West. Tucson Mountain Park was established for similar reasons as SNP—to protect outstanding and important natural resources, including saguaro cactus, and to provide for recreation (Pima County 2019b).

Other Actors—In addition to the major land management agencies profiled earlier, several other important agencies and landowners are important to the overall success of buffelgrass mitigation efforts in the region, but they own less land and have less direct management responsibility for buffelgrass mitigation: the Arizona State Land Department; land developers; other city, county, and state departments and agencies; and HOAs. While we did not interview representatives from these actors as a part of this research, we comment on their general role in regional buffelgrass mitigation.

The Arizona State Land Department own thousands of hectares of land in southern Arizona, though most of this land is outside the immediate Tucson metropolitan area. These lands were given to the State of Arizona at statehood by the federal government and are held in trust by the state for the benefit of public education and other trustees. State lands are highly diverse. In the study region, they tend to cluster in the outlying valleys surrounding the Tucson metro area. The State Land Department prioritizes two land uses (development and livestock grazing), as they are seen as maximizing the economic returns from trust land to the trustees (ALSD 2019). Therefore, a direct linkage between land developers and the State Land Department exists. Buffelgrass occurs on both state trust lands and land owned by developers or undergoing development. Disturbance of land as a result of the development process may also favor establishment of buffelgrass.

Other city, county, and state agencies are also directly engaged with invasive plant management. They own land affected by buffelgrass invasion, affect the spread of buffelgrass in carrying out day-to-day activities, or regulate land use through enforcement of rules and ordinances. For example, roads are a potential vector of spread for buffelgrass across the landscape. Decisions about weed control along roadway rights-of-way may influence the spread of buffelgrass to adjacent lands owned by the NPS, USFS, Pima County, etc. While few of these actors are significant landowners, their participation in collective action for buffelgrass mitigation may be important at a landscape scale. County and city departments that make and enforce land use regulations and ordinances (e.g., weed control ordinances) may also have an impact on invasive species spread beyond government-owned land. It is, however, beyond the scope of the current study to assess the impact of existing ordinances and code enforcement activities on buffelgrass control by actors such as developers, HOAs, and individual homeowners.

Homeowners associations are a unique actor. They set and enforce rules that apply to small areas of land within the study area but typically own or directly control only a small amount of land themselves. Therefore, the actions taken by HOAs are a reflection of the interests of their members—the homeowners in a given de-

velopment. HOAs are common in the suburban areas surrounding Tucson. As such, they are often located on the edges of the urban area at the interface with natural Sonoran Desert ecosystems where buffelgrass and saguaro cactus are common.

Key Informant Interviews

We conducted key informant interviews with three agencies in the study region: Pima County Parks and Natural Resources Department (hereafter Pima County), the NPS, and the USFS. We selected these agencies because they are proportionally the largest landowners and land managers in the study region, and a large portion of the lands they own in the region are affected by buffelgrass invasion. Buffelgrass mitigation efforts in the region are unlikely to succeed without the involvement of each of these agencies because of the amount and location of the lands they own or manage. Each agency also has an active buffelgrass mitigation program and a long history of participation in buffelgrass mitigation activities.

We interviewed three key informants at each agency. Key informants were selected based on 1) the advice of coauthor Franklin and 2) the position of each informant in the structure of the target agency. Franklin is the convener of the Sonoran Desert Cooperative Weed Management Area (CWMA), a new effort in the study region to develop a forum for interagency coordination on invasive species management, and has years of experience working with agencies throughout the study region as lead invasive species scientist for the Arizona-Sonora Desert Museum. Informants' positions within the agencies ranged from high ranking agency leaders with the ability to set policy within an organization, to middle management responsible for directing field staff, to field level personnel who implement agency policy on a day-to-day basis. Interviews were conducted during the summer of 2019. Most interviews were conducted at the informant's workplace in a closed office. Two interviews were conducted in cafés in Tucson, Arizona.

While the total number of informants, nine, was relatively small, this study population represents the majority of actors with each of the three organizations that are directly engaged with buffelgrass mitigation. For example, Coronado National Forest has one forest district level staff person responsible for implementation of invasive species management. This field-level person is overseen by one staff person in the Coronado National Forest headquarters. Finally, the leadership of the forest is divided by mission areas, with one high-level manager responsible for natural resources management, under which invasive species fall. As a result, only three people with the forest have deep knowledge of its buffelgrass mitigation efforts. Each of these individuals was interviewed for this study. Similar conditions exist in the other organizations included in the case study—a relatively small number of Pima County and NPS employees are actively engaged in buffelgrass management. Those who were most knowledgeable of the activities of each organization were interviewed. Because of the limited number of informants, we were not able to achieve theoretical saturation on topics related to interagency cooperation and collective action, nor was theoretical saturation possible. We included all key informants with knowledge of the phenomenon of interest: those directly and intimately involved in buffelgrass management and mitigation (Gubrium et al. 2012). Data from respondents within each individual organization were largely consistent. Therefore, we have high confidence in data related to actor attributes and internal institutional constraints. Due to concerns about the adequacy of the data generated by the interviews, we supplemented these data with archival research to verify and strengthen our conclusions. Together, the interview and archival data provide a complete dataset of the internal characteristics of the agencies we study and how these characteristics affect collective action.

Interviews followed a semistructured format. Questions were developed around the following research themes: 1) organizational structure and invasive species management fit within the organization, 2) perceived impacts of buffelgrass on native ecosystems, 3) approach to and level of success with buffelgrass management, 4) buffelgrass management policy and management program structure, and 5) relationship with outside entities in regard to buffelgrass management. The interview guide is available in the supplemental materials accompanying this paper. Questions included in the interview guide drew on 1) theories of collective action and CPR management to understand the institutional and social factors that enable and constrain collective action for buffelgrass management (Ostrom 2005; Poteete et al. 2010) and 2) a case study approach to understand the “how” and “why” of buffelgrass management and collective action from the viewpoint of each informant (Poteete et al. 2010; Yin 2018). Specifically, we structured the interviews around the components of the Institutional Analysis and Development Framework (Ostrom 2005), with a specific emphasis on understanding actors, institutions, and biophysical conditions and how these factors related to observed outcomes. All questions were open ended and qualitative. Interviews ranged from ≈40 min to nearly 2 h in length. All interviews were conducted by an interviewer and a notetaker. Interviews were also recorded to ensure the accuracy and detail of notes. The study design and methods were reviewed and approved by the University of Arizona Human Subjects Protection Program (protocol 1805616077).

Following each interview, the notes and recording were transcribed for analysis. We used a combined deductive-inductive, thematic coding approach to analyze interview transcripts (O'Reilly 2009). We began by establishing five general themes corresponding to our research themes and corresponding theories of collective action and coded each interview into these five broad categories. We then inductively developed more specific subthemes based on individual responses. For example, to address research theme one, organization structure and invasive species management fit within the organization, we coded the role of the individual within the organization (leadership, middle management, field level); data about the overall management focus of the organization (general resource management, conservation, preservation, environmental education); and data about how invasive species fit into the overall organizational structure (primary focus, secondary focus, uncertain). At each step of the coding process, one member of the research team coded the interviews. Coding was conducted manually and organized using spreadsheets without the aid of qualitative research software. The research team then reviewed the coding results and met to discuss and agree on final coding of the interview transcripts. In each of these subthemes, summary data was recorded to enable interpretation of results. Finally, after coding interview data from all informants from a given organization, we produced a synthesis summarizing the responses relative to our research themes.

Synthesis of Interview Data

To address our research questions of how existing and emerging institutional arrangements promote or undermine collective action among actors and across levels of governance, we synthesized interview data to understand the factors that shaped individual agency management activities. These factors mirror the themes of used in the development of the interview guide and are consistent with collective action theory, including perceptions of the problem, motivations and incentives to prioritize action, available resources and capabilities, and any organizational rules and procedures that might act as barriers to individual or collective action. We compared these results across agencies to identify areas of alignment and/or misalignment and consider the implications of alignment

and misalignment for the design of policy venues where collective action might occur. Where there was significant alignment between organizations, we expected to see greater cooperation, coordination, and engagement in venues for collective action.

Archival Data Analysis

To provide additional context for the understanding the challenge of collective action for invasive species management and to verify the themes identified in the interviews, we supplemented interview data with analysis of archival data from past efforts intended to enable regional management of buffelgrass. There were three such organizations: the Southern Arizona Buffelgrass Coordination Center, a now defunct nongovernmental organization; the Buffelgrass Working Group, a consortium of organizations interested in buffelgrass management; and the Sonoran Desert CWMA, a new organization focused on management of buffelgrass and other invasive species in southeastern Arizona. Here, we focus on the Buffelgrass Working Group because it was explicitly created as a venue for collective action, while Southern Arizona Buffelgrass Coordination Center was an independent organization that played a coordinator role for the Buffelgrass Working Group, and the Sonoran Desert CWMA is a new organization that did not yet have data available for analysis.

We analyzed the Buffelgrass Working Group strategic plan using the codes developed during the analysis of the key informant interviews to determine if and how the institutional arrangements of these collective action venues address the concerns and barriers identified by key informants. The Buffelgrass Working Group strategic plan was developed by participating stakeholders and was intended to guide regional coordination and collective action on buffelgrass mitigation. The purpose of our analysis was to determine if and how this plan provided incentives to participate in buffelgrass mitigation, improved availability of resources for participating actors, and addressed perceived barriers to participation in collective action. We used these data to supplement and validate our interview data given our relatively small sample of interview informants.

At this point we make no determination of the quality or effectiveness of collective action relative to buffelgrass management. Efforts to date have not resulted in the eradication of buffelgrass in the region but are ongoing. It may be premature to render judgment without additional data collected over time. We do assess the longevity of collective action and analyze how alignment or misalignment of institutional arrangements within and between actors affect the persistence of collective action over time and use these data in concert with related literature to improve our knowledge of invasive species management as a collective action challenge.

Results

We present our results in three sections. First, we use findings from interviews to examine how individual organizations are affected by buffelgrass, their internal resources and capabilities to address the problem, each actor's contribution to buffelgrass mitigation, and how institutional factors within each organization shape these factors. Together, these sections provide data on the attributes, resources, and institutional arrangements influencing the actions of individual actors, which in turn affect collective action (Ostrom 2005). Second, we synthesize across interviews to summarize past management of buffelgrass and draw conclusions about barriers to collective action. Third, we analyze archival data on the institutional arrangements of current and past efforts at collective action to provide additional institutional context for findings from the interviews and suggest lessons for emerging collective action venues.

Internal Factors Influencing Individual Actors

Effect of Buffelgrass on Individual Actors

All interviewees reported that their agency is negatively impacted by buffelgrass, with most citing similar concerns about the effect of buffelgrass on native Sonoran Desert ecosystems. Common themes were that buffelgrass changes ecosystems by increasing fire risk, changing plant community composition, and directly threatening the long-term persistence of saguaro cactus. Interviewees from SNP directly tied mitigation and eradication of buffelgrass to the agency's overall mission of preserving natural resources "unimpaired" for future generations: "Our primary purpose is to protect the Sonoran Desert ... particularly Sonoran Desert plants, more broadly the Sonoran Desert and sky island ecosystem. ... We see buffelgrass as a direct threat, primarily to the Saguaro and secondarily to the ecosystem." Pima County interviewees had a similar perspective, noting its mission to protect the resources in Tucson Mountain Park as a natural preserve for county residents and saguaros as a resource important to the county's tourism economy. Interviewees from the USFS provided slightly different responses. While clearly recognizing the ecological impact of buffelgrass on USFS managed lands, it was also clear that buffelgrass is just one priority out of many: "[Coronado National Forest is responsible for] activities encompassing the full range of USFS activities, from resource management to recreation. In the Coronado the focus is recreation, fire, range." This stands in contrast to an SNP respondent who stated, "Buffelgrass is the number one priority of Saguaro National Park." Importantly, buffelgrass occurs on only a small portion of the USFS lands in the study area, and the USFS also has many other invasive plant species on its lands, as well as significant recreation and fire management responsibilities.

Internal Resources Available to Each Actor

The NPS has more staff per hectare managed than other agencies studied and has devoted significant staff resources to managing buffelgrass. In addition to the staff responsible for planning and implementation of buffelgrass management, Saguaro National Park has as many as seven staff members who contribute to buffelgrass mitigation at some point during the year, plus additional volunteers and interns. The NPS also has both a regional and national team focused on non-native plant issues, so the management of invasive species has strong support throughout the organization. Pima County also has staff that have invasive species management as part of their formal duties. These staff members are also responsible for other land management duties within the natural areas program but devote significant time to buffelgrass mitigation, especially in Tucson Mountain Park. In contrast, the USFS has no staff dedicated to invasive species management. Instead, invasive species management is an "ancillary duty" of the range management staff in one forest district: "It's frustrating because we're trying to keep the momentum. There is no earmarked funding for invasives—all funding is directed at the range program, monitoring, etc." As a result, there is one staff person working on the buffelgrass problem and this person can only dedicate limited resources.

All three agencies face challenging funding environments that limit their ability to carry out an effective buffelgrass mitigation program. While SNP and the USFS generally have funds available for buffelgrass treatment each year, the timing of this funding is inconsistent. The certainty of funding is higher for SNP than for the USFS; the Coronado National Forest (CNF) has no permanent budget for invasive species treatment and instead must compete with other priorities on an annual basis: "I have funding now, but I don't have guaranteed funding every year." Dedicated funding is particularly important for the USFS, whose limited staff resources require the agency to rely on outside contractors to carry out buffelgrass mitigation work. The contracting process in turn creates a

second step delaying translation of monetary resources into action on the ground. While the CNF has been able to allocate funding to buffelgrass in past years, uncertainty surrounding funding is an impediment to developing a more robust treatment program. Saguaro National Park, in contrast, has salaries of staff members built into its base funding, has prioritized devoting staff and budgetary resources to buffelgrass, and reports that funding is generally reliable, although insufficient to treat all of the park's impacted areas. In past years, Pima County had funding allocated to buffelgrass treatment, but this support has declined, and county resources are now limited to staff resources and occasional funds for contractors.

Contribution of Each Actor to Buffelgrass Mitigation

Of the agencies included in this study, SNP has the most comprehensive and well-supported buffelgrass management program. The reasons for this are largely attributable to the mission and structure of the NPS and SNP, as compared with a particular heightened interest in buffelgrass or greater recognition of the problem relative to other actors. The NPS has a mission directly oriented toward resource preservation rather than resource use or management. All SNP interviewees described the primary mission of the park as protecting saguaro cactus and associated plant communities. As a result, at the organizational level SNP has a stronger motivation to act on buffelgrass mitigation than the USFS or Pima County. However, this commitment to management on its own lands does not appear to extend to neighboring jurisdictions. While one interviewee mentioned the Sonoran Desert Weedwackers (SDW), a volunteer organization focused on buffelgrass control in Tucson Mountain Park, as a partner organization, the other interviewees did not mention the existence of an ongoing relationship. In fact, two of the three interviewees specifically noted that the NPS does not work across boundaries: "we got extra fire money this year. ... We couldn't share it with partners unless they're next door neighbors. We could share with the Coronado [National Forest] but we didn't." In sum, relative to other actors, SNP has a robust buffelgrass control program focused on removing buffelgrass from areas popular with tourists and eliminating large patches of buffelgrass within the park's interior using herbicide application with helicopters. Despite this, SNP interviewees report that they are losing ground and that buffelgrass continues to expand in the park: "It's not a static problem, so it's like attacking a monster that's growing new heads the more you stab it."

The USFS and Pima County have a range of responsibilities largely focused on resource use and management rather than protection. While staff recognize buffelgrass is a problem, because it is not prioritized by the organization, management efforts are described as "treading water" or "trying to keep up." Interviewees reported that the forest is losing ground due to limited resources and bureaucratic challenges with applying management resources on the ground: "The forest plan modeling shows if we don't do 1 500 acres a year, then we are going to be losing ground. We use the modeling in planning but it can be hard with the funding available." The management that does take place does not apply innovative techniques or involve coordination with other actors across boundaries. This is in spite of CNF sharing boundaries with SNP and several large HOAs. The USFS does accept volunteer assistance when possible, but limited staffing resources makes this difficult. Relative to the USFS, the county places a high priority on invasive species treatment but does not have the same level of resources as the NPS to back up this interest. The county has been a leader in the region over time in both buffelgrass treatment through the SDW volunteer program and its role in coordinating and engaging other actors in the region in a more systematic and collaborative treatment of buffelgrass.

Despite the county's interest and leadership in the past, this has not translated into effective buffelgrass treatment over time.

County leaders generally perceive buffelgrass as a persistent problem and do not think the mitigation program is making a significant difference in the spread or persistence of buffelgrass in the county: "All the concerns that were raised [about buffelgrass] have not come to fruition even though the problem hasn't been addressed. [I] remember talking to Mayor Walkup and being told there was no political case to be made because there was really no evident crisis. It is limping along because the issue isn't seen as a big enough of a problem by politicians and administrators."

Despite this, leadership does support ongoing efforts to treat for buffelgrass in areas prioritized by staff and is working to develop new systems (e.g., a geodatabase of buffelgrass distribution and treatments to improve prioritization). The county made a significant regional contribution by taking a leadership role in early coordination efforts, which resulted in a collaborative program to test the effects of aerial spraying for the NPS. The county and the USFS provided funding, and the county provided the land to test aerial spraying. Federal actors did not have the ability to implement a test program due to the need for an environmental assessment under the National Environmental Policy Act (NEPA) before any aerial spraying of federal lands could take place. The county pilot program provided the data needed to complete the NEPA process. However, beyond the NPS, no other entities have used aerial spraying due to its high cost. Since the program to gain approval for aerial spraying ended in the early 2000s, coordination activities seem to have waned somewhat but are still a priority of the county.

Summary of Institutional Arrangements for Individual Action

Saguaro National Park, the USFS, and Pima County all operate in different institutional settings. These differences result in both barriers and opportunities for individual and collective action to address buffelgrass invasion on their own lands and regionally. Although they are both federal agencies, the institutions structuring decision making in SNP and CNF at the local level are quite different. These differences are the result of both the formal regulations that establish the rules the actors follow in implementing their invasive species programs and the agency traditions that have developed over time.

The interview results clearly show differences in agency tradition and institutions between the USFS and NPS. The USFS is hierarchical in structure, with institutions and traditions that reinforce this hierarchy. Management decisions in the CNF are driven by a combination of regulatory requirements, national and regional priorities, and how these priorities trickle down to the forest districts through the CNF leadership and the forest plan, which guides decision making at the forest level. Staff priorities are set primarily at the district level in response to direction from the forest supervisor's office and the forest plan. At all levels, staff seek to balance management to benefit multiple uses, including recreation, wildlife, grazing, and timber. The result of these formal and informal institutions is deprioritization of buffelgrass treatment in favor of other priorities dictated by regulations and interpreted by district-level managers and the forest plan. The USFS must meet clear regulatory requirements for administration of grazing allotments, but there are no specific requirements for invasive species management. Activities other than invasive species management, however—particularly range management—are higher priorities: "Range is a use and brings in money. It is a socio-economic activity in the area, not so much in Tucson but everywhere else. So yes, that's where we staff, that's where the money goes, it's where the public use is. I've never worked on a forest that had district folks that [invasive species] wasn't just a collateral duty." The forest plan calls for limited treatment on USFS lands but acknowledges that the recommended level of treatment will not stop the expansion

of buffelgrass on forest lands. This results in weak internal incentives for action to mitigate buffelgrass.

In contrast to the USFS, the NPS and SNP's traditions and institutions are more supportive of internal action on buffelgrass. Interviewees described the SNP and the agency in general as less rigid and less hierarchical than the USFS: "One thing is that the Park Service is very decentralized. So each park superintendent has incredible power to determine what activities go on in the park. Part of that is recognition that each park is unique." Individual parks have more flexibility to address unique resource management challenges. Local staff set priorities for treatment consistent with the mission of the park. This fits with an agency culture focused on preservation of resources in parks as they are today. In the case of SNP, this includes efforts to mitigate the impacts of buffelgrass. Saguaro National Park staff work together to establish local priorities for management, including buffelgrass, and leadership generally follow these recommendations when funds are allocated. The park superintendent has consistently supported buffelgrass treatment.

Both the NPS and USFS are subject to NEPA. As a result, major actions undertaken by the agencies to mitigate buffelgrass must follow NEPA rules. Information rules are of particular importance in the NEPA process—rules that establish how and when information is exchanged between the agency carrying out the NEPA process and other actors, including the public. While SNP has navigated the NEPA process to enable aerial spraying of buffelgrass with the assistance of Pima County, the USFS has not gone through this process and sees NEPA as a barrier to individual action: "We need to do a full EIS to do aerial spraying and the process is likely time prohibitive. EISs [environmental impact statements] scare people. [We] have looked into doing an EA [environmental assessment], but [were] told that it has to be an EIS. I can't understand how the NPS can get away with EA but we can't." The USFS has a long history of contentious NEPA processes, generally uses its own staff to complete NEPA requirements, and is frequently sued by outside actors claiming inadequate analysis of environmental impacts or violations of process rules. The NPS does not share this history. As a result, NPS was willing to go through the NEPA process to enable aerial spraying while the USFS was not.

Pima County's institutional setting is different from that of the federal agencies. Over time, the county has established an internally focused program for mitigating the impacts of buffelgrass on Tucson Mountain Park through the use of community volunteers. The institutions supporting this program seem to be largely the result of tradition and the influence of external actors on county decision makers during the 1990s and early 2000s. The county continues its treatment program, not because it is required to, but because personnel think it is consistent with the mission of Tucson Mountain Park and important for maintaining the desert ecosystem generally: "I know we have made a difference in Tucson Mountain Park and other places around Tucson that if we had not been doing what we are doing, things would have been very different."

Barriers to Collective Action

The biophysical conditions of each actor and their respective levels of interest in buffelgrass mitigation suggest a high likelihood of engagement in collective action to address the threat posed by buffelgrass. The natural resources valued by each actor are threatened by buffelgrass, namely saguaro cactus and the associated Sonoran Desert scrub plant community. The USFS, SNP, and Pima County each recognize the threat posed by buffelgrass to this valued resource and interviewees with each agency expressed that buffelgrass mitigation was at least a moderate priority. For SNP and Pima County it was a high priority. Moreover, combining efforts

Table 2

Summary of select actors' characteristics and barriers to participating in individual and collective action to mitigate buffelgrass in southern Arizona. Columns correspond with the organizations listed in the first row of the table. Rows are categories of attributes identified from interview results. Characteristics of homeowners associations (HOAs) and developers is the result of information gathered in interviews and from external sources.

	SNP	CNF	Pima County	HOAs	Developers
Org. attributes/biophysical conditions	Preservation mission; park has significant biological resources and buffelgrass invasion	Multiple-use mission; forest is dominated by uses and biological resources that are not threatened by buffelgrass	Preservation mission; parks have significant biological resources and buffelgrass invasion	Diverse goals set by member landowners; many border parks or forest and have buffelgrass management issues	Economic/profit-maximization goal; may border parks or forest; buffelgrass thrives with disturbance
Effects of buffelgrass on org.	Harms Sonoran Desert plant communities with fire and competition	Harms Sonoran Desert plant communities with fire and competition	Harms Sonoran Desert plant communities with fire and competition	Increased fire risk but may be considered aesthetically pleasing	Increased fire risk but may be considered aesthetically pleasing
Resources for individual action	High relative to other actors; staff and financial resources generally available each year	Low relative to other actors; no dedicated staff or funding	Low/moderate relative to other actors; limited staff and inconsistent funding	Unknown; resources would need to come from internal volunteers or budgets	Unknown; contribution of resources may affect profitability
Contribution to buffelgrass mitigation	Comprehensive program using staff and volunteers; invaded areas increasing	Limited program using contractors and occasional volunteers; invaded areas increasing	Moderate program using staff and volunteers; report success in Tucson Mountain Park	Unknown	Unknown
Org. Institutional arrangements	Flexibility to address unique resource issues; subject to NEPA rules	Hierarchical with goals set by national and regional offices; subject to NEPA rules	Responsive to community interests and concerns but limited internal flexibility; not subject to NEPA rules	Variable based on individual HOA codes, covenants, and restrictions; subject to local ordinances	Variable based on developer/corporate structure; subject to local ordinances
Barriers to individual action	Preservation mission on its own lands results in an internal focus	Contracting rules for external service providers; inconsistent funding; lack of organizational interest	Preservation mission on its own lands results in an internal focus, but has shown most interest in external coordination	Unknown	Unknown

SNP indicates Saguaro National Park; CNF, Coronado National Forest.

and leveraging limited resources through a coordinated mitigation program could help to overcome the serious resource constraints that all actors face. However, significant barriers to collective action result from misalignment of each actors' internal institutional arrangements and attributes (Table 2).

These barriers are reflected in the disparity of financial resources available to each actor. Funding challenges are related to three issues: 1) insufficient funding relative to the extent of the problem; 2) institutional rules controlling how funding is allocated and the processes that must be followed to spend money; and 3) consistency of funding over time. The USFS struggled with problems related to the allocation of funding from higher levels of bureaucracy and contracting requirements for paying outside entities. The CNF could not rely on funding to arrive at the time it is needed to effectively treat buffelgrass at the optimum time of year to kill plants. In addition, because buffelgrass requires retreatment for as many as 5 consecutive yr, consistent funding is needed over time, which has often not been the case: "As budgets get leaner [buffelgrass funding] has dropped off. As budgets get cut, invasives is one of the first things to drop off." Rules for contracting with external service providers were also a significant impediment to utilization of available financial resources. Contracting regulations often slowed the issuance of contracts to the point where ideal treatment windows had already passed. Pima County faced similar issues, with inconsistent funding and difficult contracting rules that required selection of inexperienced landscaping contractors rather than companies with wildland weed control expertise. In contrast, while SNP's funding was by no means assured, interviewees felt the program was relatively stable on a year-to-year basis, which allowed them to implement a consistent treatment program: "In natural resources ... we recognized that buffelgrass is our number

one issue. ... We advocate within the park to make sure that buffelgrass stays a park priority."

Differences in the attributes of actors also appear to impair consistent coordination between actors, particularly attributes related to agency traditions and institutional structures. Actors are primarily focused on treatment on their own lands and fulfilling their own agency missions—preservation for SNP and Pima County and multiple-use management for the USFS. While each of these agencies has participated in venues for collective action (described more fully later), interviewees suggest that these efforts have focused primarily on sharing information and have yielded few efforts to systematically coordinate mitigation efforts or share resources. Saguaro National Park and Pima County are facing what interviewees regard as overwhelming buffelgrass challenges on their own lands and have not done much to look beyond their own treatment programs to a regional coordination strategy. Interviewees identified a single instance of cross-agency resource sharing, where the county and the USFS contributed resources that enabled SNP to systematically test the efficacy of different treatment approaches on NPS lands, including aerial spraying of herbicides using a helicopter. County respondents also report a relatively high amount of coordination and cooperation with other actors, though it is unclear if these arrangements are routine. County respondents report working with other organizations on volunteer efforts to share equipment and expertise and plan eradication strategies on lands with a common boundary: "I feel great about some areas ... where we have worked hard on one side of the fence and the BLM or the USFS or the NPS has the other side of the fence. You have to work hard together in an area to be successful. We have some areas where the NPS has come on board nicely." While field staff report the existence of formal memorandums of understand-

ing (MOUs), leadership staff did not mention any formal administrative mechanisms between the county and other actors.

From the interviews there is no indication that the CNF is interested in or would have the capacity to engage in transboundary cooperation with other entities. There is also limited evidence that the CNF regards buffelgrass as a particular management priority relative to the many other challenges it faces. This is clearly a reflection of informants' understanding of the multiple use mandate and tradition of the USFS. They see buffelgrass as just one management challenge among many. More pressing challenges to ensuring forest health and ensuring long-term use and enjoyment of the forest by the public include range management to prevent ecosystem degradation and fire prevention and management to prevent large-scale fires. Finally, overall management direction comes from national and regional offices; the USFS is highly hierarchical and the lack of engagement in invasive species management locally is in part a reflection of the priority the national and regional offices of the USFS place on invasive species management relative to other multiple use goals: "Funding is an issue. Staffing is an issue. National priorities aren't focused on it. Areas where there is the most noise made is where the focus is. ... Things are driven by what the public wants. The current focus ... is on public use."

Past, Current, and Emerging Venues for Collective Action

Past Venues for Collective Action: the Buffelgrass Working Group

By the mid-2000s, it had become abundantly clear to federal land managers and conservation biologists that buffelgrass posed a serious threat to the sustainability of the Sonoran Desert landscape. Moreover, it was also clear that individual land managers' efforts were insufficient to address the buffelgrass problem. In response, actors in the region have developed or initiated a number of policy venues and forums to increase coordination and cooperation on buffelgrass. These efforts have met with mixed successes: actors in the region have cooperated—and some continue to cooperate—on scientific research, information sharing, and public outreach, with some significant success in building scientific understanding of buffelgrass treatment options and increased public awareness. On one occasion, actors worked collaboratively to secure external federal funding for buffelgrass eradication projects that aligned with federal wildfire prevention objectives. But these injections of federal funds have been short-lived. When this article was written in 2019, cooperative efforts in the region had for some time focused largely on information sharing and strategic planning, while individual land managers either struggled to address the problem with inadequate funding and resources (as in the case of SNP, CNF, and Pima County), or simply chose not to take action (as in the case of HOAs and developers).

In 2006, an informal coalition of agency representatives, non-profit organizations, city and county leaders, and university researchers met with the goal of improving buffelgrass management across jurisdictions (BWG 2008). The more formal Buffelgrass Working Group was established later that year, comprising core members of the informal coalition, as well as organizations who had contributed financially to buffelgrass management efforts through the Cooperative Ecosystem Study Unit. Members signed a formal memorandum of understanding that outlined the Buffelgrass Working Group's purpose and structure, as well as each members' obligations. The Buffelgrass Working Group became the primary regional venue for collective action to mitigate the impacts of buffelgrass.

The Buffelgrass Working Group's initial priority was to prepare a 5-yr strategic plan for proactive buffelgrass management, which was released in 2008. The plan identified 12 management goals needed to minimize buffelgrass spread and impacts in the region. These goals included the development and funding of a lead or-

ganization to coordinate collective action; ongoing scientific research; extensive public outreach; and development of local ordinances to prompt action by all landowners in the region. Interviewees widely acknowledged that the plan's public outreach efforts had been successful, noting that community members are knowledgeable about buffelgrass, and community volunteers have organized monthly buffelgrass pulls for well over a decade. The Buffelgrass Working Group was also the primary venue for coordination between federal and local actors for development of a successful Wildland Fire Resilient Landscapes funding proposal that provided a short-term injection of financial resources to the region for buffelgrass mitigation. Yet 10 yr later, many of the Buffelgrass Working Group's management goals have yet to be realized. Subsequently, the Southern Arizona Buffelgrass Coordination Center was created to coordinate collective action, but without funding, the organization was dissolved in 2016, and its functions were assumed by the Arizona-Sonora Desert Museum, a local conservation and outreach nonprofit. The Southern Arizona Buffelgrass Coordination Center and SNP were both successful in securing federal funding for buffelgrass eradication, but both grants were part of short-term programs and have not led to long-term funding for continuous eradication efforts.

Emerging Venues for Collective Action

In 2018, the Arizona-Sonora Desert Museum initiated a new forum for collective action—the Sonoran Desert CWMA. CWMAAs are an approach to invasive plant management devised in Idaho in the late 1990s when state and federal land managers began to recognize invasive aquatic weeds as a threat to regional ecological health requiring cooperation across a wide range of landowners and other actors with a stake in managing invasive plants. Since then, CWMAAs have formed across the United States. CWMAAs typically serve as a platform for relevant actors to share information and other resources and engage in region-wide strategic planning. CWMAAs also encourage and facilitate the creation of MOUs between members, allowing them to formalize agreements about the actions that each member will take, as well as how resources will be developed, used, and shared among members. Today, the emerging Sonoran Desert CWMA is the primary policy arena where multiple actors interact and engage in, or work toward, collective action to manage buffelgrass in Pima County. As a new and emergent form of collective action, the Sonoran Desert CWMA lacks a sufficient track record for analysis here, but it nonetheless provides evidence that actors on the ground continue to identify coordination and cooperation as crucial needs in their efforts to address buffelgrass.

Discussion

Collective Action on Buffelgrass in Southern Arizona

The results of our interviews with SNP, the USFS, and Pima County provide data on both contemporary actions by these organizations to mitigate buffelgrass and their impressions of regional collective action to manage buffelgrass over time. Here, we synthesize the interview results to identify areas of effective and ineffective coordination and offer explanation for why collective action formed around certain activities but not others. In summary, we find evidence that successful collective action to share information on the science and impacts of buffelgrass took place but limited evidence that coordinated buffelgrass mitigation efforts have otherwise occurred. The difference in outcomes between information sharing and on-the-ground mitigation activities are attributable to the complex nature of invasive species as a collective action problem and dissimilar internal institutional arrangements, attributes, and biophysical settings of each actor.

At the time of this study, collective action on buffelgrass mitigation was near its historical low point. A venue for coordination between agencies and other actors, the Buffelgrass Working Group had stopped functioning. The emerging Sonoran Desert CWMA, which in many ways was intended to fill the void left by the Buffelgrass Working Group, had been formed but was in the very early stages of identifying the scope of its work, the actors who would be involved, and the group's immediate priorities. This moment of lack of regional coordination was evident in the interviews, with most respondents focused on their own agency's lands and responsibilities and making only limited reference to ongoing work with other organizations.

Despite this, the effects of past collective action on information sharing and public engagement are clear in the buffelgrass mitigation programs of each agency and the attitudes of the interviewees. Each agency recognized a significant increase in public awareness about the problems posed by buffelgrass and credited the Buffelgrass Working Group in achieving this goal. It was also clear that all interviewees clearly understood the threat of buffelgrass to Sonoran Desert plant communities, regional economic development, and the built environment. All entities were using information developed through the Buffelgrass Working Group process on the approaches to buffelgrass eradication, namely repeated herbicide spraying or manual pulling over a period of at least 5 yr, the length of time needed to deplete the soil seed bank. Pima County specifically noted its role in enabling helicopter spraying by SNP as a marquee example of what was possible through regional coordination on science and management information.

Significantly, collective action to share information and scientific findings about management of buffelgrass did not challenge any of the agencies' traditions or internal institutional arrangements. None have rules restricting participation in information sharing about management with other agencies or the public. In fact, the USFS and SNP have rules under NEPA and other laws that require information sharing. Other actors that were members of the Buffelgrass Working Group, including the USGS and the University of Arizona, also had specific scientific- and information-sharing missions that were directly supported by engagement in the Buffelgrass Working Group. Therefore, collective action to share information had a relatively low barrier of entry for the agencies involved.

In contrast, collective action to engage in coordinated mitigation efforts across different land ownerships ran into several barriers: differences in agency attributes (preservation vs. multiple use missions and traditions; locally generated management priorities vs. priorities generated by national and regional policy makers and regulations) and agency institutional arrangements (the process of allocation of funds, staffing levels, contracting rules, etc.). Each agency had strong incentives—and in some cases legal obligations—to ensure as much buffelgrass mitigation took place on its own lands as possible. This limited their ability to engage in coordinated regional action that might be more effective at reducing buffelgrass in the region, but that could potentially direct management resources away from one agency in favor of another.

The incentives that individual agencies face to focus primarily on their own individual lands are likely exacerbated by the fact that individual agencies lack sufficient funding to fully treat invasions on their own lands. All three agencies expressed concern that they were not keeping up with the problem on their own lands. If actors had greater access to funding, they might well be more open to working across agency jurisdictions to treat buffelgrass where it would have the greatest ecological benefit for the region as a whole. In the current funding landscape, however, land managers may feel forced to focus their limited resources on their own lands. This finding is consistent with past research, which shows that in the context of limited funding, weed management programs fo-

cused on a single jurisdiction treat larger areas than collaborative programs (Hershner et al. 2007).

Limited collective action on management did occur in unique circumstances when a potential infusion of additional resources meant that the benefits of collective action outweighed the costs. The primary example of this was the Wildland Fire Resilient Landscapes initiative. In this instance, in order to receive funding, federal and local agencies needed to work together to develop a regional project. Collective action was enabled by a recognized need to enlarge the resources available to all actors and the availability of a forum—the Buffelgrass Working Group—for this coordination to take place. In the time since the Wildland Fire Resilient Landscapes initiative, federal support for cooperative, multiagency, landscape-level management has waned. In the absence of other similar opportunities to expand regional economic resources, coordination failed to persist. This example does, however, highlight the potential role for federal land managers in encouraging and supporting cross-agency cooperative efforts to address invasive species.

Beyond the demands placed on each agency to meet internal management goals, lack of staff resources severely constrained the ability to engage in collective action. The USFS has never had dedicated invasive species staff. The scale of the problem on SNP lands demands that its staff focus inward rather than outward. Pima County at one time was the most engaged in regional coordination efforts, but over time as the problem persisted and major ecological consequences did not emerge (e.g., a large destructive wildfire), high-level interest seemed to wane and staffing resources declined. Lack of staff at the USFS and Pima County has resulted in both relying on contractors to carry out work, with significant resources devoted to navigating the contracting process rather than engaging with other entities to coordinate activities. Even where agencies shared boundaries—a circumstance that would seem to encourage collective action because of the likelihood that buffelgrass would spread from one agency's land to the others—little to no collective action was reported.

Understanding the Nature of Invasive Species as a Collective Action Problem

Thus far, we have discussed invasive species as a collective action problem to be managed by those who contribute to or are affected by the problem. But scholars often note that there are different types of collective action problems with different available solutions and, thus, different recommendations for managers and decision makers (Graham et al. 2019). Our case study points to two types of collective action problems as particularly relevant for invasive species management—public goods problems and CPR problems.

Many scholars identify invasive species management as a public good (Ayer 1997; Toleubayev et al. 2007; Graham 2014; Niemiec et al. 2016). In classical terms, public goods are those that are nonexcludable and nonrivalrous in consumption, such as lighthouses and national defense, such that they are most effectively provided by a single government entity (Ayer 1997). Government agencies have traditionally taken a leading role in addressing invasive species management, and many scholars have posited or assumed that invasive species most resemble a public goods problem, where private actors have little or no incentive to take action and thus action is required by the government (Ayer 1997; Graham 2014; Ervin & Frisvold 2016).

Other scholars have posited that invasive species are a CPR problem (Kruger 2016) or a hybrid good with characteristics of both public goods and CPRs (Ervin & Frisvold 2016). Classic CPR problems—such as community management of forests and fisheries—occur when multiple actors have access to and incentives

to use resources whose consumption is rivalrous, setting up the famous “tragedy of the commons.” Unlike public goods problems, CPR problems may be best governed through coordination among and between the users who contribute to and are affected by problems (Ostrom 1990). Authors that characterize invasive species as CPR problems focus on the way that many individual actors play a role in contributing to the spread of a species, such as coordination across ownerships (Kruger 2016) and the development of chemical resistance to pesticides (Ervin & Frisvold 2016). These characteristics of the problem are rivalrous: lack of cooperation by some actors may undermine the effectiveness of mitigation actions by others, and overuse of pesticides may reduce efficacy for others. From this perspective, solutions should not be top down or agency based but should rely on coordination and cooperation among relevant actors.

Our findings suggest that invasive species can present a complex, *dual* collective action problem that includes the public goods problem of gathering and sharing information about an emergent problem and a CPR problem of coordinating effective mitigation across multiple land managers. Both the public good and CPR aspects of the problem are important for understanding the development, or lack thereof, of collective action for invasive species mitigation. In our case study, collective action around the production and sharing of information is well developed, but persistent barriers continue to hinder collective action around invasive species mitigation in the region.

First, information about the science and management of invasive species is a public good (Ervin & Frisvold 2016). Scientific information is nonrival—one land manager’s use of information does not undermine another’s ability to do so—and it is both difficult and a contravention of public policy to exclude others from using nonpatented scientific information. In addition, production of scientific information entails costs that often make public agencies, rather than individual actors, best suited to provide this public good. Our results tend to confirm that information about invasive species and their management is best characterized as a public good problem and best produced by agencies that have the resources to do so and then freely share with others who can use the information. In our case, information about buffelgrass management was developed cooperatively between Pima County and SNP and freely shared with other actors in the region, and information sharing was the most common form of cooperation that interviewees identified. There are few barriers to sharing information: doing so is a low-cost action for an individual agency, and information sharing could potentially enhance individual land managers’ ability to address the problem on their own lands. This finding is also consistent with other studies that show that information sharing, such as monitoring arrangements and knowledge of socioecological systems, are the most common elements of invasive species management programs (Graham et al. 2019).

Other scholars, however, suggest that invasive species control itself has some of the characteristics of a CPR problem, at least within settings such as our case study, where individual land managers must manage individual parcels. While one land manager’s use of information does not affect another land manager’s ability to do the same, land managers’ ability to control invasive species is dependent upon other nearby land managers’ efforts to do so. Thus, if some actors are unable or unwilling to engage in invasive species control, the efficacy of others’ efforts is diminished, making invasive species management at least weakly rivalrous and suggesting that resolution of the collective action problem will require coordination of control strategies across land ownerships (Ervin & Frisvold 2016). Here, our study highlights the potential barriers that might undermine effective coordination among individual actors. We find that individual actors have different incentives and priorities for devoting resources to invasive species control; that

sharing of resources may be infeasible; and that these problems are exacerbated by insufficient funding and staff resources.

In addition, invasive species themselves are extractive users of a CPR—the natural environment in a given place. In our case, buffelgrass is a “user” of Sonoran Desert scrub plant communities. It diminishes the value of this community for other users, carrying out this activity without reference to the human institutions that have developed for the use and management of these resources. Therefore, institutions that enable treatment of natural resources as private goods—the land tenure system that divides the landscape and the institutional arrangements structuring the activities of the individual landowners—are undermined. The result of this collective action failure is continued spread of buffelgrass and its continued use of additional resources while siloed, inward-focused resource managers struggle to locate and eradicate new infestations.

Management Implications

Effective management of buffelgrass and invasive species generally requires collective action across heterogeneous organizations (Albers et al. 2010; Jarnevich et al. 2015). In the case of buffelgrass invasion in southern Arizona, many actors are interested in mitigating the impacts of buffelgrass on native Sonoran Desert scrub plant communities. Some of these actors have been able to produce information about buffelgrass mitigation techniques, and actors have engaged in extensive collective action around sharing and dissemination of this information. However, differences in the attributes of actors, institutional arrangements guiding their behavior, and lack of resources relative to the extent of the problem have limited the development of long-term, effective collective action to control the species’ spread in the region. Our case study of buffelgrass management shows that careful consideration of invasive species management as a collective action problem reveals nested collective action problems involving different types of public goods and CPRs.

After arrival and initial establishment, invasive species present multiple collective action challenges. To effectively mitigate an aggressive species such as buffelgrass, actors must work together on the coordination, gathering, and sharing of information related to mitigation and coordination of mitigation activities across jurisdictions. Our research suggests that information production most resembles a public goods problem, where actor(s) with sufficient incentives and resources can effectively produce information for others who would benefit from it. In southern Arizona, two agencies worked together to produce information that was valuable to a wider range of heterogeneous actors; and this information has been widely and effectively disseminated through an evolving set of institutions, starting with the Buffelgrass Working Group and continuing through the more recent Sonoran Desert CWMA that has emerged to take its place.

While we characterize production of information as a public goods problem, our study also shows that the dissemination of that information is a multiactor process, requiring collective action on the part of multiple actors. In our case, information has been widely disseminated because the benefits of information sharing are high and the barriers are low. Each actor gains resources that improve their ability to achieve their internal goals, without risk of violating internal institutional rules and norms. At the same time, we also note that actors in the region have struggled to create, maintain, and support the cooperative organizations that support this kind of information dissemination. The initial organizations that were developed for this purpose are no longer in existence, and the organization that has emerged to take its place—the Sonoran Desert CWMA—is supported largely by an area nonprofit. Management efforts to address invasive species should consider not only the importance of information production as a public good

but also the importance of supporting the organizations that provide infrastructure and institutional support for directing and disseminating research and information.

Our study also suggests that the nature of the collective action problem shifts as actors attempt to move from information sharing to addressing the core of the problem—mitigation on the ground. While a single, well-resourced agency might well be able to produce the necessary information on control strategies, implementing control strategies tends to require more coordination among adjacent land managers, since the efficacy of one manager's mitigation may be affected by others. Here, our case study shows that collective action on mitigation efforts has lagged behind collective action on information production and dissemination. Our study also identifies some of the key barriers that limit both individual and coordinated control efforts between federal land management agencies, including internal institutions, cultural traditions and mandates, and the availability staff and other resources. All of these barriers are exacerbated by insufficient funding, which further limits agencies' ability to look beyond their own efforts to "keep up" with the problem and consider more regional strategies.

From a management perspective, this suggests that where some land managers lack sufficient incentives or resources to address invasive species, individual and collective efforts to address the problem are unlikely to simply emerge on their own. Instead, some actor(s) need to identify the barriers to effective action and coordination and identify mechanisms that will help to overcome those barriers. In our case, this occurred on a one-time basis when federal agencies made funding available for coordinated, cross-boundary eradication aimed at reducing fire risk. Efforts to identify and overcome barriers might also occur locally, if jurisdictions are able to develop and fund programs that provide a similar set of incentives and resources for coordinated action.

Regardless of whether these efforts are initiated locally or federally, however, our case study shows that approaches to solving these problems must include improved knowledge of internal institutional structures and the opportunities and barriers they present to collective action, the preferences of heterogeneous actors when presented with models of future ecosystem conditions absent coordination, the factors that prevent individuals within different organizations from following through on commitments to participate in collective action institutions, and how each of these conditions affects the availability and persistence of resources for mitigation. Together, improved knowledge of the relationships between these factors may provide new approaches to proactive management of emerging 21st century resource management challenges, from invasive species to emerging diseases.

Declaration of Competing Interest

None.

Acknowledgments

Trang Weitemier provided assistance with interviews, and Mauricio Nunez-Regueiro and Max Yue Li aided in conceptualization of the research.

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