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Weed Control as a Collective Action Problem: Quantifying group effects on individual behavior, and clarifying the theoretical frame

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WEED CONTROL AS A COLLECTIVE ACTION PROBLEM: QUANTIFYING GROUP EFFECTS ON INDIVIDUAL BEHAVIOR, AND CLARIFYING THE THEORETICAL FRAME

By

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Weed Control as a Collective Action Problem: Quantifying group effects on individual behavior, and clarifying the theoretical frame

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Weeds reduce the biodiversity and productivity of agricultural systems, and are a problem both around the world, and in Montana. Weeds are challenging to control because their effective dispersal mechanisms enable cross-boundary colonization, and so managers must engage diverse groups of private landowners. Researchers have recognized weed control is a collective action problem, but there is little research quantifying the role of collective factors on an individual's decision to control. To fully understand the motivations behind independent weed control, I initiated a study to quantitatively assess different types of landowners and their weed control behaviors, the relationship between collective interest variables and individual landowners' willingness to engage in weed control behaviors. I identified a k-means cluster analysis as a way to segment the Montana landowner population, and the Collective Interest Model as a way to understand the influence of collective factors on an individual's decision to control for weeds, while holding individual factors constant. I surveyed 4,500 Montana landowners, and analyzed results using descriptives and ordinarily least squares regression. I found five different groups of landowners, and that collective factors, such as an injunctive norm and the belief weeds are a cross boundary problem, were significantly correlated with willingness to engage in three different weed control behaviors. This suggests if weed control outreach explicitly promotes collective messages, it may be able to more effectively engage landowners. In addition, I believe that weed control has been mis-classified in the literature as a common pool resource problem, instead it should be considered a public good problem. I present reasoning that weeds are a public good problem and draw on solutions to public good problems generally and adapt them to weed control.

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Chapter 1

Introduction

In 2013, land managers from several Montana-based natural resource agencies and NGOs gathered to discuss how to better promote conservation and stewardship on private lands. At the meeting were outreach and extension professionals from organizations that worked on fire mitigation, estate planning, human wildlife conflict, and weed control. Their collaboration became referred to as the Natural Resource Collaboration Working Group (NRCWG). Each individual group sought to address basic information gaps challenging their efforts, but more importantly, all the managers felt their outreach strategy was falling short of necessary and desired impact. In general, the outreach approach adopted by these managers had been based on the assumption that if landowners learned about the importance of an issue they would become concerned and take action. Over time, members of the group began to recognize, as the social science literature has documented, that behaviors are instead driven by complex suites of factors and that changing behavior – encouraging stewardship – requires a careful and concerted effort.

After interfacing with researchers in the Human Dimensions (HD) Lab at UM, the NRCWG realized that to improve the effectiveness of their outreach strategies, they would to broaden their focus to the full suite of variables often correlated with behavior, not just attitudes. To understand the motivations behind natural resource management behaviors, the NRCWG pooled funding for two master's students and the implementation of a statewide survey. The group aimed to address three focal topics: fire mitigation, weed control, and human wildlife interaction, and goals for the survey were described in a whitesheet (Metcalf & Christiaens, 2015). Overarching goals were to "aid natural resource stewardship managers across the state in identifying the most effective avenues for connecting with the public in their operation areas" (Metcalf & Christiaens, 2015, p. 1). Specific objectives for the study were to understand Montana landowners' attitudes and values, constraints, preference for information sources, and pathways for inspiring behavior change (Metcalf & Christiaens, 2015). The group acknowledged the limitations of past approaches and wanted to look for "novel approaches to natural resource conservation outreach and education" (Metcalf & Christiaens, 2015, p. 1). In setting these goals, the NRCWG recognized the complexity of what motivates landowners and was looking for a new model that reflected this complexity.

Four years after the first NRCWG meeting, I was chosen as one of the master's students to work on the project. Part of my charge was to translate the broad goal of encouraging stewardship into specific management recommendations. To design and implement this research, I was part of a collaborative team with Dr. Alexander L. Metcalf and Crystal Beckman. We each focused on a single topic area; I chose to work on the weed control component. As I developed the weed control aspects of the research, I worked with the NRCWG to identify resource specific goals, and then translated those goals into tangible items to include in a survey of private landowners. Through this process I was able to investigate the understudied role of collective action as a source for novel means of encouraging stewardship behaviors. Now, as I write this thesis, I believe the results from this project serve to advance our knowledge of collective conservation behaviors and inform the design of more effective stewardship outreach.

Starting the research process

My undergraduate degree was in geology and environmental studies, so to orient myself to the field of weed control I began by reviewing papers about both the biological and social aspects of weed control. Coming on to the project I was aware that traditional explanations of behavior change had limitations. Specifically, social psychology literature has long discussed the limitations of outreach based simply on raising awareness. This form of outreach has theoretical roots in Azjen and Fishbein's (2005) Theory of Planned Behavior which suggests an individual's values inform their attitudes, on which behavioral intentions are formed, and behaviors based. While this theory has been useful for explaining variation in behavior, it has also misled many into believing attitude change is the clearest pathway to behavior change. On the contrary, many studies have demonstrated that changed attitudes frequently do not correlate with behavior change, and other methods are more likely to be effective (Heberline, 2012).

As I moved forward, I looked for a model of behavior that incorporated a variety of factors in addition to attitudes. From my initial exploration of the literature it was clear weed control was a particularly challenging issue because weeds disperse across property boundaries. In areas with significant private landownership this meant weed control would require a collective effort across a landscape, an effort which may be bolstered or undermined by the connections and coordination (or lack thereof) among neighboring landowners. Recognizing that these collective factors were important, I narrowed my search for a model of weed control behavior to those that incorporated collective factors as well as individual and contextual variables. One such model, used to study invasive species control in Hawai'i (Niemiec, Ardoin, Wharton, & Asner, 2016), had adapted the Collective Interest Model (CIM), a theory from political science previously used to explain political activism. While Niemiec et al. (2016) used the CIM to explain weed control "activism," such as teaching a neighbor how to control, I wanted to use the model to look at independent weed control behaviors – the individual actions of landowners, not their collaborative or cooperative efforts. I felt the model could be adapted to understand weed control in Montana because it incorporated comprehensive suite of behavioral motivations.

Findings from the weed control literature have suggested collective factors are important, yet research on collective factors in weed control is limited. Despite wide agreement that effective weed control must be coordinated across ownership boundaries, weed control research has just begun to investigate the role of collective dynamics in determining weed control behavior (Aslan et al., 2009; Epanchin-Niell et al., 2010; Klepeis, Gill, & Chisholm, 2009; G. R. Marshall, Coleman, Sindel, Reeve, & Berney, 2016; Yung, Chandler, & Haverhals, 2015). Many of these studies focused on collaborative groups and cooperative behaviors, rather than independent action (Graham & Rogers, 2017; G. R. Marshall et al., 2016; Reid et al., 2009). My literature review demonstrated that collective factors are integral to weed control, but also exposed a lack of knowledge of exactly how collective factors influence individual weed control behaviors.

Biophysical Properties of Weeds

To fully understand weed control, I needed to understand some of the basic biophysical properties of weeds and how they spread. I reviewed the biophysical literature of weeds to understand what effective weed control entails, and the challenges to achieving effective landscape wide weed control. Understanding the ecology of weeds was critical to understand both landowners' weed control behavior, and their cross-boundary relationships with other landowners.

"Weed" is a colloquial term for an undesirable plant species that has dominated an ecosystem without being intentionally cultivated by people (Baker, 1974). While weeds are often non-native plants not all non-native plants are invasive, and introduced plants may be invasive in some areas and not in others (Simberloff et al., 2013). What distinguishes weeds is that they are considered "opportunists," meaning they can tolerate a range of climatic and soil conditions and quickly colonize disturbed land (Baker, 1974). The ability for weeds to handle ecological variation allows them to keep growing when other plants go dormant due to stressful conditions (Robbins, 2004).

Weeds also have successful reproduction strategies that allow them to spread quickly and persist on the landscape. For example, in some instances weeds can propagate without a pollinator, allowing for a rapid increase in population size (Baker, 1974). Weedy species often spread slowly at first, but once a stimulus triggers their growth, the population can boom (Baker, 1974). Weeds frequently maintain a long-lasting seed bank that will germinate under appropriate conditions, making weed control a long-term process (Baker, 1974). These adaptive strategies make weed control difficult, because at first the plants may seem innocuous, and then once population grows it is difficult to control (Hobbs & Humphries, 2012).

Impacts of Weeds

There is general agreement that weeds degrade the ecosystems where they are found. Weeds outcompete native plants lowering biodiversity in wildlands and can alter ecosystem services such as the flow of water and nutrients (Mulin et al., 2000; Baker, 1974). When weeds significantly alter an ecosystem, the ecosystem may transition from a historical state into a new stable state, or "novel ecosystem" (Simberloff et al., 2013). There is a debate about the role of novel ecosystems, with some viewing them as degraded ecosystems, while others place no value judgment and simply recognize them as ecosystems where structures and functions have changed.

However, weeds have significant economic impact, especially in agricultural systems where their presence reduces quality, efficiency and functionality in production (Bridges, 1994). This can happen through pathways such as loss of water, reduced forage and increased cost of production (Bridges, 1994). Implementing weed control also increases the workload of the landowner, and some herbicides may put the landowner at risk for ill health effects (Bridges, 1994). Some impacts of weeds are difficult to measure because their spread is hard to detect in remote locations, and their damage hard to quantify in wildland areas (Bridges, 1994; Mulin et al., 2000). Past efforts have roughly quantified the effect of weeds at $20 billion annually (Bridges, 1994). Despite exact figures, it is clear that weeds have a profound negative economic and aesthetic impact on the landscapes they invade.

Ecologically based weed control

Most of the biologically adaptive strategies that make weeds successful also make weed control difficult. Weeds operate on broad temporal and spatial scales and effective weed control must extend beyond individual patches of weeds, and consider ecosystem drivers that enable invasion (Sheley & Smith, 2012). In several works, Sheley and co-authors present a framework to approach weed control from a holistic ecological view, what they call Ecologically Based Invasive Plant Management (EBIPM) (Sheley, 2006; Leffler & Sheley 2012; Sheley & Smith, 2012). EBIPM categorizes the underlying reasons for the weed invasion into three categories: site availability, species availability, and species performance (Sheley & Smith, 2012). One of the primary conditions for a successful weed invasion is disturbed land, often linked with human use (Hobbs & Humphries, 1995). This approach gives land managers a framework to dissect their weed infestation and build a control plan based on the unique biophysical characteristics of the infested area.

Social Aspects of Weed Control

The spread and propagation of weeds is a biophysical process facilitated by human behavior (Baker, 1974). As such, effective weed control extends beyond the ecology of weeds to grapple with human land-use factors (Hobbs & Humphries, 1995). Hobbs and Humphries (1995) argued not only should the dynamics of invasion process and the characteristics of the ecosystem being invaded be considered when developing weed control, but also the impacts by humans. While the biological underpinnings of weeds are well understood, what is required to navigate the social landscape to engage a critical mass of landowners and implement changes that curtail the ecological drivers of weeds in an area vastly understudied.

One difficulty in engaging landowners is that perceptions of weeds and weed control vary widely, and these perceptions contribute to whether or not a landowner is willing to control (Norgaard, 2007). In some cases, landowners are aware a plant species is invasive, but they still see value in maintaining it (Marshall, Friedel, van Klinken, & Grice, 2011). For example, Marshall et al. (2011) found Australian ranchers felt the invasive buffel grass gave them a sense of hope for their livelihood because it was drought tolerant forage. While they recognized the negative ecosystem impacts, they felt those were outweighed by the economic benefits (Marshall et al., 2011). Buffel grass provides a perfect example of how the narrative around whether an introduced species is good or bad depends on cultural factors that shape an individual's perspective.

Emotional responses and the language around IS, both weeds and animals, can shape the public perception. In some cases, residents grow attached to “cute” IS, and find removal unacceptable (Selge, Fischer, & van der Wal, 2011, p.3094). just as the public can sometimes become attached to charismatic megafauna, attachment has also been documented for several weed species (Selge et al., 2001, Kalnicky et al., 2014;Marshall et al., 2011). On the other end of the spectrum, the militant language often used to describe control, such as “battling an invasion,” implies an almost violent connotation (Simberloff et al., 2012). In a similar vein, some people may see IS as a threat to an area and believe it has the potential to ruin the “culture” of a place (Selge et al., 2011). The acceptability of different management plans is often contingent on whether or not a species is considered good or bad by the public, regardless of the environmental impact of the species (Selge, Fischer, & van der Wal, 2011; Sharp, Larson, & Green, 2011; Sullivan, York, An, Yabiku, & Hall, 2017; Urgeson, Prozesky, & Esler, 2013).

Acceptability of IS control is not only based on the perceptions of the species, but also attitudes and beliefs about control methods. In northern California, historical misuse of herbicides by the U.S. Forest Service produced both mistrust in the government and suspicion and protest of future chemical treatments (Norgaard, 2007). In 1997, the Forest Service aerially sprayed herbicides over an area of public land to control for knapweed. This land was culturally important and used by the Karuk Tribe, loggers, back-to-the-landers, small scale farmers and miners that inhabited a small community near the area (Norgaard, 2007). After the spraying, these different segments of the population held divergent perspectives on risk posed by herbicide use. While the Forest Service said the herbicide was safe, some community members, recalling when the government promoted DDT, did not accept these government assurances (Norgaard, 2007). Norgaard (2007) found women were warier of herbicide spraying because they believed some herbicides can cause miscarriages and birth defects (Norgaard, 2007). The spraying also put the Native population at a higher risk of exposure because they used the area to hunt and gather wood for weaving (Norgaard, 2007). The Forest Service had not tested to see if the herbicide was safe for human ingestion, possibly putting tribal members at risk (Norgaard 2007). This case study shows how weed control efforts can have unique effects on various segments of the population and leading to variation in perceptions of weed control even within one small community.

Landowners have a unique relationship with IS because IS can impact the value of their property. Their attitudes toward IS are partly informed by calculating the risk of damage the species could cause. Fischer and Charnley (2012) investigated the relationship between risk perception and weed control behaviors of Oregon landowners. They found that being aware of, and concerned about, invasive plants were significantly correlated with weed control. However, 34 percent of landowners who were aware of weeds, and 36 percent who were concerned about them, still did not control (Fischer & Charnley, 2012). Fischer and Charnley (2012) suggested this occurred because (1) concern is on a spectrum, with some landowners "concerned," but not overly so, and (2) landowners perceived that weed control efforts were "futile" (p. 384). Fischer and Charnley (2012) found that even in a fairly homogeneous population, weed control behaviors varied because of differing perceptions of weeds, and varying willingness and ability to control for them.

Risk perceptions of IS can also manifest in unexpected ways because as a species become naturalized, people often get used to them. For example, Kalnicky et al. (2014) found that residents' attitudes of an invasive frog species in Hawai'i, responsible for eradicating endemic species and increasing noise pollution, were not universally negative (Kalnicky et al., 2014). In fact, landowners with more frogs on their property had less negative attitudes toward them, and some residents even held positive views (Kalnicky et al., 2014). Despite governmental efforts to raise awareness on the negative impacts of the frogs, these residents maintained a positive attitude (Kalnicky et al. 2014). This study shows that attitudes towards invasive species are not always intuitively predictable.

Even when landowners have high levels of awareness and concern, weed control is often limited by material resources or knowledge. Aslan et al. (2007) investigated factors that influenced ranchers' ability to control for yellow star thistle, *Centaurea solstitialis,* on the slopes of the Sierra Nevada Mountains. This species impacted over 90 percent of interviewees, and most ranchers (86 percent) had attempted to control yellow star thistle (Aslan et al., 2007). Researchers found most of these control efforts provided only short-term, inconsistent solutions and were not often based on management recommendations (Aslan et al., 2007). This ineffective control was caused by a poor understanding of weed dynamics, heterogeneous landscape that called for multiple methods, and lack of money and time (Aslan et al., 2007). Individuals simply believed their own personal resources and efforts were insufficient to make a difference in weed control.

Cross-boundary considerations

Research has started to examine how perceptions of neighbors' properties and behaviors influenced landowners' weed control efforts. While cross-boundary tensions have long been recognized, researchers posit it was historically easier for landowners to cooperate with each other because rural landowners were mostly primary producers and weeds interfered with their livelihoods (Fiege, 2005; Klepeis et al., 2009; Yung & Belsky, 2007). Currently, rural areas are experiencing with an influx of amenity owners, or "rural-restructuring," and landowner's material frustrations are now compounded by new landowners who are less effective controllers and are unaware of the social norms surrounding weed control (Yung & Belsky, 2007; Gosnell, Haggerty, & Travis, 2006). Rural areas, in the US and across the world, are currently contending with wave of new landowners who buy rural property for the lifestyle rather than the economic prospects.

These new, often amenity, landowners are often not well integrated in the community and can be unaware of norms pertaining to weed control (Epanchin-Niell et al., 2010; S. Graham, 2013; N. A. Marshall et al., 2011; Yung & Belsky, 2007). In Montana, Yung and Belsky (2007) observed that ranchers cooperated across fence lines because of established "norms of neighborliness" (Yung & Belsky, 2007, p. 694). They found, "landowner neglect of weeds was viewed as irresponsible and 'unneighborly' because weeds along fence lines spread to adjacent properties" (Yung & Belsky, 2007, p. 695). As new landowners moved in, older residents of an area felt like these new neighbors created a "hole" where the norms of neighborliness no longer held, breaking down the foundations of trust and cooperation (Yung & Belsky, 2007).

In some cases, landowners are able to overcome social constraints and organize, sometimes in conjunction with an extension agent, to form collaborative weed control groups. These groups typically facilitate joint weed control efforts, such as spray days or applying for group funding (Hershdorfer et al., 2007; Reid et al., 2009). These groups can successfully recruit members because their mere existence creates the injunctive social norm that controlling for weeds is something that 'ought to' be done (McKiernan, 2017). Studies have observed that these groups give landowners space to commiserate about their weed problems, share information, and foster a sense of trust (Graham & Rogers, 2017; McKiernan, 2017). However, these weed control groups are the exception rather than the rule, and most landowners engage in weed control individually, if at all.

The importance of collective factors is clear for joining collaborative weed control groups, however my focus on independent weed control behaviors on private property presents a fundamentally different set of questions. Weed control literature has just begun to examine the role that collective factors play in driving independent weed control. Yung et al. (2015) found that norms and social expectations contributed to an individual's decision to control for weeds on their own property in the Nine-Mile Valley in Montana. There, landowners cited 'weeds coming from neighbors' as the most significant barrier to effective weed control (Yung et al., 2015). Although only 17 percent of landowners thought their neighbors were controlling for weeds, more than half of landowners who did control, did so to be a good neighbor (Yung et al., 2015). Not only do landowners recognize the material impacts of a neighbor not controlling for weeds (e.g., because seeds spread to their property), they are also motivated by the social pressure to ‘be a good neighbor’ and engage in control behaviors themselves. These forces and dynamics are worthy of further exploration and are the focus of the remainder of my thesis.

Theoretical Background on Collective Action

While weed control studies have suggested the importance of collective factors on individuals’ decisions, few studies engage meaningfully with collective action theory. Other fields, such as political science and economics, have developed robust theories of how collective factors influence individual decisions to engage in a variety of behaviors. Collective action problems are contained in the broad category of social dilemmas, the dynamics of which have been explored in economics (Olson, 1968), political science (Kollock, 1998; Schelling, 1978.), and natural resource literatures (Ostrom, 1990; Hardin, 1965; Lubell, 2002). These literatures have explored myriad conditions that inspire or constrain collective or cooperative action using economic games, thought experiments, and empirical case studies. Through this body of work, authors have identified many constraints to collective action, and scenarios when constraints are successfully negotiated and collective responses enabled. These constraints and solutions can be translated from political science and economic realms to help inform weed control research and practice.

By carefully considering the collective nature of weed control, I sought to examine the constraints for action and to draw on lessons from other disciplines to propose methods for increasing weed control behaviors. For example, weed control is simultaneously a ‘weakest link’ problem and a ‘threshold aggregator’ problem. In weakest link problems, “the smallest individual contribution fixes the overall provision of the public good” (Sandler, 2015, p. 198). In other words, the actor that contributes the least toward the public good, or does not contribute at all, determines the outcome for all other actors. A classic example of a weakest-link problem is a disease quarantine, where containment is only effective when every person with the disease is quarantined; one detractor fixes the overall provision of the public good at zero. Weed control is *similar* to a weakest-link problem because weeds spread across boundary lines (Fiege, 2005; Reid et al., 2009; Yung et al., 2015; Marshall et al., 2016), so one property without weed control can reduce the effectiveness of others' control efforts. Of course, weed control is not a quintessential weakest link problem because landowners can realize at least some benefits from weed control, even if they must continually address incoming seeds from a sole, detracting neighbor.

The problem of weed control also has elements of a 'threshold aggregator' problem, where collective efforts must surpass some baseline level before benefits accrue (Sandler, 2015). A classic example of a threshold aggregator problem is climate change mitigation; efforts of one contributor are likely ineffective unless they are matched by similar actions of enough other people to achieve a global threshold for change. Weed control is *similar* to a threshold aggregator problem because the benefits of controlling weeds on one property are limited unless enough neighbors also control their weeds (Graham, 2013). Free-riding is a problem in many collective action problems, including threshold aggregator problems, because each independent, individual action is likely inconsequential, yet collective action is needed to provision the good, and benefits of the public good are "non-excludable," meaning they are available to all, including non-cooperators (Sandler, 2015). Still, weed control is also not a perfect example of a threshold aggregator because, once again, individuals can realize at least some benefit from controlling weeds on their property, even if seeds are continually incoming from all neighbors. Here, the collective nature of this problem is likely lower (or at a minimum, different) on large properties where seed dispersal is slower, and the effects of neighbors is diminished.

Considering the elements of weed control that resemble a weakest-link and threshold aggregator problem illuminates potential constraints and solutions to controlling for weeds. In both problems there needs to be a high level of contribution from actors. This is a difficult goal to achieve. Additionally, constraining in threshold aggregator problems, the first individuals who engage in the collective actions often have the highest costs (Chong, 1991). For example, the first landowners control for weeds may incur a higher cost because weeds are spreading back onto their properties at a high rate from neighboring landowners who are not controlling. This may make it particularly difficult to encourage landowners to start the process of weed control. However, as I explore further in Chapter 3, research from other disciplines has uncovered strategies to mobilize volunteerism and overcome exactly these problems.

Implementing Collective Action Theory

My review of the literature indisputably identified weed control as a collective action problem and demonstrated a wide variety of collective factors that were influencing landowners' decisions to control for weeds. This research relied almost exclusively on qualitative research methods and data. To quantify the role of collective factors, I knew I needed a flexible model that would allow me to incorporate a diverse array of both collective and individual motivations and constraints. During my literature review I found Niemiec et al.'s (2016) use of the Collective Interest Model (CIM) to explain weed control behavior in Hawai'i. I decided to use the CIM to develop the survey because it was a simple and flexible model that explained individual behavior in collective action problems.

$$EV = [(p_i + p_g) * V] + B - C$$

Eq. 1. Collective interest model

The CIM models an individual's engagement in collective behavior (EV) based on an individual's perception of: their personal efficacy (p_i), group efficacy (p_g), their valuation of the outcome of the collective action (V), and the costs (C) and benefits (B) of engaging in the action (Finkel & Muller, 1998). Personal efficacy is conceptualized as the extent to which an individual thinks his or her personal actions can affect the provisioning of the public good (Finkel & Muller, 1998). Whereas, group efficacy measured an individual's perception other will contribute to the collective action, and the group will be successful (Finkel & Muller, 1998).

The (CIM) was first developed to look at political protest behavior in Eastern Germany by Finkle, Muller and Opp (1998). They developed the model to describe how individual and collective variables drove the decision for an individual to take part in political protests, which they considered unconventional behavior. Traditional theories of political protest posited that when an individual's grievance was high enough they would protest (Finkel et al. 1998). These theories were detailed in Olson's (1968) *Logic of Collective Action,* which assumed actors would not protest unless the benefits of protesting outweighed the costs (see Chapter 3 for a more detailed review). Olson (1968) concluded that in large groups, rational individuals would recognize their actions do not make much of a difference in achieving the collective goal, and to maximize their benefits, instead of contributing to the collective goal, they would choose to 'free-ride' off the work of the group. However, Finkle et al. (1998) recognized not all individuals were free-riders and believed there were also collective, rather than self-maximizing, motivations driving individuals. To test the role of collective motivations, they measured how collective factors, such as the social experience of protesting, combined with individual factors, such as the fear of getting caught by police, to determine an individual's "utility calculus" of deciding to protest (Finkle et al. 1998). To partially account for the 'free-rider problem' they cited research that suggested individuals overestimated their impact on obtaining the collective good, making them more likely to participate than expected (Finkel et al., 1998). They found that if personal and group efficacy were both high, an individual would not become a free-rider, and instead participate in a protest to achieve a public good (Finkel et al. 1998). Their conclusions formed the basis of the CIM.

The CIM was later brought into a natural resource context by Lubell (2002), who adapted it to explain the motivations behind environmental activism. He used the CIM to explain general environmental activism (Lubell, 2002), climate change activism (Lubell & Vedlitz, 2006), and air quality activism (Lubell, Zahran, & Vedlitz, 2007). In all three contexts, Lubell, and his coauthors, found both individual factors, such as race, and collective factors, such as trust in the government, to be significant for engaging in environmental activism. Lubell's work demonstrated the CIM could be adapted to explain behavior in engaging with natural resource issues.

Yau (2011) adapted the CIM away from activism behaviors and used it explain collaborative behavior in shared housing in Hong-Kong. Many residents of apartment buildings in Hong Kong were co-owners of the entire building, and, as a group, they are responsible for upkeep in their common spaces, such as the lobby (Yau, 2011). Yau (2011) was interested in what motivated tenants to organize and maintain collective spaces. Yau (2011) found that both individual and collective action variables were significant in residents' willingness to attend or organize meetings around upkeep duties. Yau's (2011) study demonstrates the adaptability of the CIM to not only explain collective in a non-political setting.

Niemiec et al. (2016) used the CIM to explain the control of an invasive tree, albizia, in the Puna District of Hawai'i. There, the authors used a case study of an invasive tree that dropped branches after hurricane events causing substantial damage to homes and cars. Niemiec et al. (2016) used the CIM to measure residents' collaborative efforts to help the community control albizia, or albizia control "activism." The behaviors the measured included helping a neighbor remove albizia, teaching a neighbor how to control albizia, and removing albizia from a community space (Niemiec et al., 2016). They found that both individual factors, such as knowledge of how to control, and collective factors, such as reciprocity where positively associated with albizia activism (Niemiec et al., 2016).

Niemiec et al. (2016) demonstrated the CIM could be used to explain invasive control, however their results were generated in a very unique study area and are not generalizable elsewhere. Specifically, their case study looked at an unusual species causing dramatic damage which may have elevated the sense of risk and the need for the community to respond collectively (Niemiec et al., 2016). They also used snowball sampling in a small community which may have biased their sample to more actively controlling community members (Niemiec et al., 2016).

Implementing the CIM in our Study Site

Based on Niemiec et al.'s (2016) adaptation of the CIM, I felt that the CIM could be adapted to explore individual weed control behaviors in Montana. Our application of the CIM differs from previous research in a few prominent ways. Our study measures landowner's willingness to control for weeds in general. Weeds are a long term relatively low-risk problem in Montana, and there may not be the push for timely action. Weeds have persisted on the landscape in Montana for over 100 years, and their lasting presence may suggest to landowners weed control is futile. This history of weeds in my study site may lead to very different perceptions of the risk of weeds and if weed control can be successful.

Montana is an ideal study site to explore the role of collective factors in weed control because the history of land-use in the state has led to a landscape where, today, almost all landowners are affected by weeds. Weeds were introduced into Montana in the 1880's, when they were most likely intermixed with crop seeds planted by homesteaders (Fiege, 2005). Weeds were then able to flourish and spread when homesteaders abandoned their land due to farm failures during the Dust Bowl (Fiege, 2005). After the Dust Bowl, landowners started to return to the area, and roads and railways were built to accommodate the growing population (Fiege, 2005). This transportation infrastructure provided new vectors for weeds to spread, and lead to the almost ubiquitous presence throughout the state (Fiege, 2005).

Montana is also an appropriate site to the role of collective factors in weed control, because weeds have been formally classified as a collective problem in Montana as early as the 1920s. In the 1920s weeds were codified into Montana law as a "common nuisance," weed control was enforced because weeds "interfered with the rights of an entire group" (Fiege 2005, p33). The designation of a common nuisance indicates an early awareness that weeds were a cross boundary issue. While the law created a formal structure to deal with weeds, communities of landowners also informally came together to work on cooperate efforts to control weeds (Fiege, 2005). Montana has a long legacy of both weeds and collective attempts to control them, making it an ideal study site to examine how collective factors inform individuals' weed control decisions.

Not only am I applying the CIM in a context where the risk perceptions of weeds are likely different, I am also adapting the CIM to understand independent, rather than collaborative, behaviors. Most weed control studies considering collective factors have looked at cooperative control efforts. All studies using the CIM have sought to explain collaborative behaviors, like protesting or teaching a neighbor how to control weeds, where more than one actor is engaging in the behavior. Instead, I applied the CIM to look at independent actions of landowners on their private property. I was uncertain if this application would work, because even though weed control is a collective action problem, landowners do gain private material benefits from controlling for weeds on their property, even if no other landowners are controlling. In contrast, to gain material or social benefits from participating in a political protest, other actors must also protest. Based on the flexibility of the CIM in other contexts, I felt that it would be adaptable to parse out the role of collective factors in independent action when an individual can still gain private benefits.

Building the Survey

After deciding to use the CIM to shape our survey, the research team presented our framework to the NRCWG and emphasized the unique collective nature of the model. The NRCWG also felt it had high potential to explain anecdotally observed variance in stewardship behavior. To adapt the model to my context, I asked Christiaens, the Missoula Country Weed District Manager, what the most important behaviors was he was trying to promote. This lead to an in-depth discussion about the biophysical nature of weeds and how the spread (by attaching to cars, pets, clothing, wind), and to the variety of almost daily actions landowners need to take to diminish the spread of weeds from all these vectors.

Another complication is that once weeds have propagated weed control needs to be both site and species specific (B. Christiaens, personal communication, October 27, 2016). For example, spraying herbicides needs happen at certain times of the year, (B. Christiaens, personal communication, October 27, 2016), and the disturbed area needs to be quickly replanted. Weeds have a seed bank that can last multiple years, so weed control is a long-term process that may entail different methods year to year (B. Christiaens, personal communication, October 27, 2016). This makes it difficult to specify control behaviors that would be applicable to landowners across the state of Montana (B. Christiaens, personal communication, October 27, 2016).

Still, behavioral research requires the identification of clear, actionable behaviors, and it was difficult to simplify the diverse and conditional actions needed for effective weed control. After discussions about the need to specify, Christiaens (personal communication, October 27, 2016) identified the most effective ways to approach weed control, including meeting with a professional to make a long-term plan that incorporated the biophysical elements of the landowner's property. Making a long-term plan is rare, and in order to measure a range of behaviors we also identified other behaviors. These included: washing your personal gear/ clothing after being in an area with weeds, washing your vehicle after being in an area with weeds, buying weed-free alternatives (weed free forage, weed free gravel), and checking your property for weeds. We also identified four behavioral intensions, and measured landowners' willingness to: work with an extension professional to develop a weed control plan for their property, use herbicides to control weeds, release bio-control (insects) to control weeds, and spend time pulling weeds from their property (Table 1).

Methods

Survey Development

After identifying the behaviors, we struggled with how to measure them, given the lack of previous quantitative research in this area. Weed control is a long-term prospect, so assessing if a landowner has ever taken weed control action is not a good measure of adequate control behavior. For example, if a landowner has sprayed for weeds in the past, but did not reseed the area, they could have created bare ground and facilitated rather than curtailed weed propagation. To get at the frequency of control, I measured behaviors on a three-point scale: never, sometimes, always.

I developed other survey questions to establish independent variables using past CIM literature (Lubell, 2002; Niemiec, 2016), and adapting it to address weed control in Montana. For example, Niemiec et al. used concern about biodiversity to measure how much a landowner values albizia control. I felt, after discussion with my committee, this might not resonate with Montana landowners and instead considered other factors that might concern Montana landowner about weed on their property (Table 1).

A draft of the survey was first presented to my committee November 8, 2016. After incorporating edits and refining the survey, we presented another draft to members of the working group, and other representatives of resource agencies. This group also agreed with the theoretical approach of the CIM and identified additional information about where landowners get information on different resource issues they wanted incorporated into the survey. We incorporated questions asking about preferred sources of information and willingness to take certain actions on a variety of issues.

Table 1. Variables and scales for the survey constructs organized using the collective interest model

	Variable	Survey Item	CIM designation	Scale
Dependent-Behavior	Behavior 1	Wash your personal gear/ clothing after being in an area with weeds	EV	3-point Never, Sometimes, Always
	Behavior 2	Wash your vehicle after being in an area with weeds	EV	3-point Never, Sometimes, Always
	Behavior 3	Buy weed free alternatives (weed free forage, weed free gravel)	EV	3-point Never, Sometimes, Always
	Behavior 4	Check your property for weeds	EV	3-point Never, Sometimes, Always
Dependent-Behavioral intension				
	Behavioral intention 1	Work with an extension professional to develop a weed control plan for your property	EV	5-point Very unwilling-Very willing
	Behavioral intention 2	Use herbicides to control weeds	EV	5-point Very unwilling-Very willing
	Behavioral intention 3	Release bio-control (Insects) to control weeds	EV	5-point Very unwilling-Very willing
	Behavioral intention 4	Spend time pulling weeds from your property	EV	5-point Very unwilling-Very willing
Collective				
	Cross-boundary belief	If neighboring property owners take action to reduce the spread of weeds, it will reduce the number of weeds on my property as well	P_g	5-point Strongly disagree-Strongly agree
	Reciprocity- notice or hear	If you take actions to control weeds, neighboring property owners will notice or hear about it	P_g	5-point Strongly disagree-Strongly agree
	Reciprocity-motivate to act	If you take actions to control weeds, it will motivate neighboring property owners to take similar actions	P_g	5-point Strongly disagree-Strongly agree
	Group efficacy	Together, neighboring property owners and I can effectively control weeds in our area	P_g	5-point Strongly disagree-Strongly agree
	Area wide satisfaction	How satisfied or dissatisfied are you with the current efforts to control weeds in your area?	V	5-point Very unsatisfied to Very satisfied
	Network centrality-ask opinion	Has anyone ever asked you for your opinion on weed control?	C/B	2-point Y/N
	Network centrality- influence opinion	Has anyone ever tried to influence your opinion on weed control?	C/B	2-point Y/N
	Descriptive norm	Do most people in your area believe you should be taking steps to control weeds on your property?	C/B	5 point Strongly disagree-Strongly agree
	Injunctive norm	Do you believe most people in your area are taking actions to control weeds on their properties?	C/B	5-point Strongly disagree-Strongly agree
	Sense of Community		C/B	
		I feel a strong sense of community with my neighbors		5-point Strongly disagree-Strongly agree
		If there is a problem in my area, people here get it solved		5-point Strongly disagree-Strongly agree
		I often take an active role in solving area problems		5-point Strongly disagree-Strongly agree
		I have an influence over what this community is like		5-point Strongly disagree-Strongly agree
Individual				
	Personal efficacy	My personal actions can help control weeds on my property	P_i	5-point Strongly disagree-Strongly agree
	Concern		V	
	Weeds decrease enjoyment	Weeds decrease my enjoyment of my property		5-point Strongly disagree-Strongly agree
	Weeds decrease the economic value	Weeds decrease the economic value of my property		5-point Strongly disagree-Strongly agree
	Weeds decrease the productivity	Weeds decrease the productivity of my property		5-point Strongly disagree-Strongly agree
	Weeds negatively impact the appearance	Weeds negatively impact the appearance of my property		5-point Strongly disagree-Strongly agree
	Weeds limit my ability to use	I have enough time to control weeds on my property		5-point Strongly disagree-Strongly agree
	Money	I have enough money to control weeds on my property	C/B	5-point Strongly disagree-Strongly agree
	Time	I have enough time to control weeds on my property	C/B	5-point Strongly disagree-Strongly agree
	Confidence in ability to control	I am confident in my ability to identify weeds	C/B	5-point Strongly disagree-Strongly agree
	Confidence in ability to identity weeds	I am confident I know how to effectively control weeds on my property	C/B	5-point Strongly disagree-Strongly agree
	Trust the government to control for weeds	I trust the government to control for weeds	C/B	5-point Strongly disagree-Strongly agree
	Age	Age	C/B	

Biocentric environmental belief	The balance of nature is delicate and easily upset	C/B	5-point Strongly disagree-Strongly agree
Anthropocentric Environmental belief	Economic growth should be given priority, even if the environment suffers	C/B	5-point Strongly disagree-Strongly agree
Education	Education	C/B	5 Categories: Grade school, High school/ GED, Some college, College graduate, Post graduate
Income	Income	C/B	9 Categories: >$9,999, $10,00-1$9,999, $20,000-$39,999, $40,000-$59,999, $60,000-$79,999, $80,000-$99,999, $100,000-$119,999, $120,000-$139,999, $140,000->$140,000
Acreage	Acreage	C/B	Open response
Gender	Gender	C/B	Male/ Female

Sampling

In drawing our sample, I set several parameters to make sure we were sampling the population of interest to our funders. In Montana, average parcel size varies across the state, with smaller parcels in the west and larger in the east. My sampling frame included non-public landowners owning between .5 and 6,000 acres of land outside of incorporated city limits. I set these parameters to focus our study on smaller landowners because small landowners collectively own a large portion of the land base and have diverse landownership goals. I regionally stratified the sample (i.e., western, central, and eastern regions; Figure 1) to ensure adequate representation of landowner perspectives across the state. I drew an initial sample of 4,500 landowners (1,500 per region) using the Montana cadastral data (Base Map Service Center Montana State Library, 2017). I pretested the questionnaire with graduate students and faculty at the University of Montana, employees of the Montana Department of Natural Resource and Conservation, and extension professionals. To capture mid-size owners across this range of variation, I set my upper limit of acreage at 6,000 acres. This size was developed with input from land managers, who felt that it represented a mid-size parcel size in eastern Montana. I also established a lower limit of 0.5 acres, a minimum size for a landowner to have a noticeable and impactful weed problem. I chose landowners that lived outside city limits because they were more likely to have to deal with the other cross-boundary issues, wildfire preparedness and human-bear conflict, we were addressing in our survey.

To get a representative sample from across the state, we stratified the state into three regions (West, Central and East) by combining the seven Fish Wildlife and Parks regions (Figure 1). While my findings reported in this thesis focus on statewide results, we sought data which could provide regionally specific results to members of the working group. We sent 1,500 surveys to each region, and weighted responses according to the process outlined by Vaske (2008) to estimate statewide parameters (Eq 2).

$$Weight = \frac{Poplulation\ \%}{Sample\ \%}$$

$$Population\ \% = \frac{Number\ of\ landowners\ in\ stratum}{Number\ of\ landowenrs\ across\ strata}$$

$$Sample\ \% = \frac{Number\ of\ respondents\ in\ statum}{Number\ o\ frespondents\ across\ strata}$$

Equation 2. Procedure for calculating weights of a sample as outlined by Vaske

I then adjusted these weights, so the mean of the weight is one. This maintains the original sample size (Vaske, 2008; Eq. 3).

$$Adjusted\ Weight = \frac{Weight}{Mean\ of\ the\ Weights}$$

Equation 3. Procedure for normalizing the weights as outlined by Vaske 2008

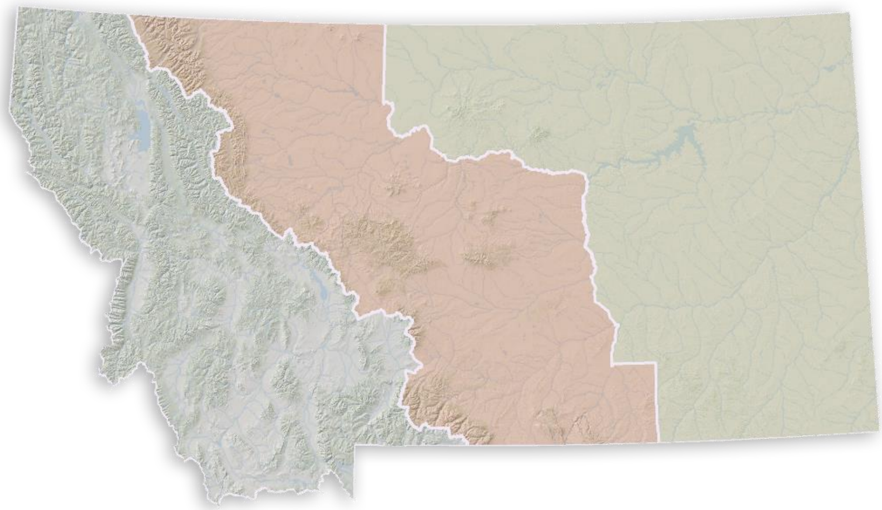

Figure 1. Map of Montana with the three regions used in survey implementation

Analysis

To check for normality, I plotted histograms of all dependent variables. To see how variables were distributed across the population, I ran descriptive statistics (mean, median standard deviation) on all variables.

OLS Analysis

I used Ordinary Least Square Regression (OLS) to identify factors significantly correlated with willingness to engage in weed control behaviors, a standard method for applying the CIM (Lubell, 2002; Yau, 2011; Niemiec, 2016). I considered using a stepwise function instead of OLS, but felt the statistical literature was uncertain about the benefits of stepwise since they are sensitive to the order in which variables are entered, and statisticians do not believe they provide unbiased results (Thompson, 1995). When assessing my OLS results, I felt that it was important to cast a wide net for significant variables, and I set my significance cut-off at .10 level, which has been done in previous CIM analysis (Lubell 2002).

However, after running regressions on the behavior dependent variables, my results indicated the behaviors themselves, and how we measured them, proved problematic. One of the obvious problems was that behaviors were not applicable to everyone. For example, weed-free forage and gravel is not available in every area or sought by all landowners. Our measurement failed to differentiate between landowners who “never” bought weed-free alternatives because they were not available or landowners who have the option but do not choose it. Similarly, it was possible that a landowner never drove or walked through weedy areas so reporting “never” for “washing a vehicle/ clothing after being in an area” may indicate “not applicable” more than “applicable, but never done.” This would create a downward bias in our measurements of weed control behaviors.

While checking property for weeds is applicable to all landowners this measure was also problematic. Almost all landowners reported sometimes or always checking their properties for weeds (70%), and almost as many reported washing their personal gear after being in an area with weeds (68%). When presenting these two statistics, many extension agents and land managers did not believe they were representative of what they were seeing on the ground. This measure also suffered from vague wording that may have led to a range of interpretation. For example, an absentee landowner could *always* check their property whenever they were there, but they may only be residing on their property for a few weeks a year. In contrast, a full-time resident could *sometimes* check their property, and that could mean checking once a week year-round. Another potential problem with the measures was that Montana landowners are legally required to control for noxious weeds on their property and face a fine if weeds are found. This could have led to an over-reporting of weed control behaviors.

Additionally, I measured these behaviors on a three-point scale which did not create adequate variation in the responses. None of the responses showed a normal distribution. I attempted to normalize the results through several transformations, however the data still remained skewed.

Due to these problems, I instead used a suite of willingness questions as my dependent variables. These included “work with an extension professional to develop a weed control plan for your property,” “use herbicides to control weeds,” “release bio-control (insect) to control weeds,” and “spend time pulling weeds on your property” (Table 1). These questions more accurately reflected the range of actions taken to control for weeds. I conceived of willingness as a behavioral intention, which has been seen as “the closest cognitive antecedent of actual behavioral performance” (Azjen & Fishbein, 2005, p. 188). This is not an ideal dependent variable because there is still a gap between intention and behavior and many people do not act on their intentions (Ajzen & Fishbein, 2005). However, willingness has been used in other assessments of the CIM (Lubell, 2002; Yau, 2011) and behavioral intentions are common dependent variables in behavior research.

Results and implications of the OLS analysis are discussed in detail in Chapter 2. There I resume my discussion of the collective nature of weeds and the effects on individual weed control behavior. Below I provide descriptive results from the landowner survey, including a typology of landowners which has been used to inform outreach strategy by members of the NRCWG.

Cluster Analysis

While OLS results can reveal broad patterns, I wanted to know how landowners varied in their individual resources and behaviors. Grouping different sections of the population is a tool often used in marketing categorize sections of a population, which allows people to tailor messages to certain groups (Punj & Stewart, 1983). Tailored messages allow land managers to target certain groups, because, generally, these messages only mobilize a portion of the audience. Targeted messages are likely more effective than blanket outreach campaigns to the entire population (Punj & Stewart, 1983). To segment the population, I performed a k-means cluster analysis. To test for differences in parcel size between clusters I performed a one-way ANOVA on acreage grouped by cluster.

Results

Descriptive Statistics-Main findings

Initial sample size was reduced to 4,424 after we removed duplicate and incorrect addresses. Respondents totaled 1,327 for a response rate of 30 percent. Based off histograms, all independent variables except acreage were normally distributed across the population. Acreage was skewed right, with many small properties, and few large properties. Gender was also skewed, with two-thirds of landowners being male, typical of landowner populations. Descriptive statistics for all variables are shown in Table 3, with results weighted to provide statewide estimates, not simply descriptions of our sample.

Table. 3 Survey constructs and descriptive results from survey items

Variable	Survey	Mean	Standard Deviation	Cronbach Alpha
Dependent variable 1	Work with an extension professional to develop a weed control plan for your property	3.72	.926	
Dependent variable 2	Use herbicides to control weeds	3.95	.991	
Dependent variable 3	Release bio-control (Insects) to control weeds	3.727	1.01	
Dependent variable 4	Spend time pulling weeds from your property	3.83	.992	
Group efficacy	Together, neighboring property owners and I can effectively control weeds in our area	3.85	.884	
Satisfaction	How satisfied or dissatisfied are you with the current efforts to control weeds in your area?	2.98	.983	
Network centricity- ask opinion	Has anyone ever asked you for your opinion on weed control?	1.28	.449	
Network centricity- influence opinion	Has anyone ever tried to influence your opinion on weed control?	1.27	.445	
Injunctive norm	Do most people in your area believe you should be taking steps to control weeds on your property?	1.54	.499	
Descriptive norm	Do you believe most people in your area are taking actions to control weeds on their properties?	1.44	.497	
Sense of Community		3.34	.77	.843
	I feel a strong sense of community with my neighbors	3.52	.932	
	If there is a problem in my area, people here get it solved	3.47	.913	
	I have an influence over what this community is like	3.16	.953	
	I often take an active role in solving area problems	3.2	.926	
Personal efficacy	My personal actions can help control weeds on my property	4.11	.773	
Concern		3.93	.83	.907
	Weeds decrease my enjoyment of my property	4.09	.903	
	Weeds decrease the economic value of my property	4.03	.909	
	Weeds decrease the productivity of my property	3.91	.994	
	Weeds negatively impact the appearance of my property	3.46	.896	
	Weeds limit my ability to use my property in the ways I want	3.46	1.108	

Money	I have enough money to control weeds on my property	3.28	1.122
Time	I have enough time to control weeds on my property	3.18	1.116
Confidence in ability to control	I am confident in my ability to identify weeds	3.48	1.086
Confidence in identify weeds	I am confident I know how to effectively control weeds on my property	3.43	1.077
Trust in government	Trust the government to control for weeds	2.17	.958
Age	Age	64.32	12.88
Biocentric environmental belief	The balance of nature is delicate and easily upset	3.77	1.019
Anthropocentric environmental belief	Economic growth should be given priority, even if the environment suffers	2.25	1.052
Acreage	Acreage	Median=20	
Education	Education	Mode=Some College	
Income	Income	Mode= $60,000-$79,000	
Gender	Gender	Male 63.5% Female 28.8%	

Results from Cluster Analysis

After running the k-means cluster I found the landowner population had five, relatively equal sized clusters. I named these clusters: “Doing it all,” “Doing all they can,” “Bootstrapping it,” “Can’t do much,” and “Unconcerned.” Descriptive results from the cluster analysis are presented below (Table 4). I found significant differences in parcel size between “Doing all they can” and “Bootstrapping it” as well as between “Can’t do much” and “Bootstrapping it.”

Table 4. Means displayed for each variable used to determine cluster, separated by cluster

	Doing it all	Doing all they can	Bootstrapping it	Can't do much	Unconcerned
Statewide membership percentage	25.3%	19.5%	18.1%	17%	20.3%
Mean acreage	444	187	718	329	461
Median acreage	12	17	40	20	14
Concern	4.27	3.8	4.19	3.8	3.49
I have enough money to control weeds on my property	4.11	2.48	2.28	1.81	3.96
I have enough time to control weeds on my property	4.09	3.27	2.27	1.85	3.68
I am confident in my ability to identify weeds	4.22	2.41	4.15	2.22	3.9
I am confident I know how to effectively control weeds on my property	4.21	2.51	3.88	2.03	3.92
Wash your personal gear/ clothing after being in an area with weeds	2.29	1.72	2.17	1.73	1.34
Wash your vehicle after being in an area with weeds	2.21	1.56	2.01	1.56	1.28
Buy weed-free alternatives (weed free forage, weed free gravel)	2.10	1.53	2.04	1.43	1.21
Check your property for weeds	2.94	2.34	2.85	2.24	2.58

Discussion

Descriptive Statistics Discussion

Respondents were generally well educated (51% of landowners reported having a college degree or higher), older (average age was 64 years), and male (69%), with high income (34% reported over $100,000 of annual household income), consistent with landowner populations in the US. We found respondents had slightly, but statistically significantly, more wild hay acres and non-quality acres.

I found that landowners generally had a high sense of concern about weeds. Almost all landowners thought that weeds decreased their enjoyment of their property (81.6%), limited their ability to use their property (81.4%), and decreased the economic value of their property

(76.5%). Most landowners were aware that weeds were a cross boundary problem (85%), and that the actions they took affected their neighbors. While most landowners reported taking a variety of actions they do not believe that others around them are controlling for weeds (60.5%). This presents an interesting contradiction where most landowners report taking actions to control weeds, and believe there is an expectation to control for weeds, but generally do not think others around them are doing the same. This disparity shows there is room for growth in landowner's perception that those around them are controlling for weeds, possibility promoting trust in the collective.

Most landowners report they are monitoring their property for weeds (93%), and, in comparison, other weed control efforts are much less popular. While I question the validity of high response for monitoring property for weeds, I found other weed control behaviors were far less popular. While almost all landowners check their property for weeds, 68 percent of respondents wash their personal gear after being in an area with weeds, 63 percent of respondents wash their vehicle, and 51 percent of respondents buy weed-free alternative materials. The difference between checking your property and these behaviors could be due to a lack of resources. While check your property if fairly costless, landowners may not have access or funds to buy weed-free materials. My results indicate that behaviors to reduce the spread of weeds may be an area of growth for land managers.

In general, landowners had a high sense of personal efficacy, however my results indicated some clear material needs. While most landowners felt their individual actions could help control for weeds (75%), only half of landowners reported having the resources they needed to control for weeds. These results had some slight regional variation, with more landowners in the Central and East reported having enough time. Once again this indicates landowners have material constraints that limit their ability to control for weeds.

Landowners also believe that together with their neighbors they can implement effective weed control. While this is encouraging, it may be influential in a landowner's decision to control because most landowners do not believe others are controlling. While the vast majority of landowners understood that weeds are a cross boundary problem (85%), less than half of landowners believed those around them are taking actions (39.5%). Most landowners have not been asked their opinion (73.6%) or had someone try to influence their opinion (73.1%) on weed control. This lack of discussion about weed control could be contributing to the perception others are not controlling. This suggests a disconnect; where the majority of landowners both report taking actions to control for weeds and do not think others are controlling. This presents an opportune area for land managers to create messaging that both raises awareness for actions people are taking and acknowledges the expectation to control for weeds.

Discussion by Cluster

Doing it all

The "Doing it all" group represented the "model citizens' of in the weed control world, and about a quarter of the landowner population fell into this category (26.7%). They had a high concern about weeds on their property, lots of time and money, and the highest engagement in weed control. They also believed that their neighbors expected them to control for weeds. This was the largest group across the state and in each region.

Management implications

My results suggest that “Doing it all” should be a low priority for extension agents, because this group has the tools they need and is already engaging in control. They also already feel social pressure to control for weeds. However, members of this group could be prime prospects try lead workshops or speak to their neighbors about weed control because they are active controllers. These landowners could both spread weed control knowledge throughout their communities and increase awareness of the expectation to control. This group is most willing to take independent actions, like using herbicides or pulling weeds, and may need encouragement to speak to an extension professional.

Doing all they can

The “Doing all they can” group was also concerned about weeds on their property but reported lower levels of weed control possibly because of material constraints. This group was not satisfied with weed control in their area, however, they report they do not have enough time or money to control for weeds. While they believe their neighbors expect them to control, they do not think their neighbors are controlling themselves. This group had the smallest parcel size on average (187 acres).

Management implications

My results suggest this is a prime group to target because this group wants to control but needs access to additional resources. This group may respond to social messaging, because they think there is an expectation to control, but do not think other people are not meeting the expectations, and so they may feel defeated. By highlighting that others are also controlling for weeds this could engage social norms and encourage this group. “Doing all they can” is willing to both take individual action, like using herbicides or pulling weeds, and speak to an extension professional. By connecting them to an extension professional they may be able to figure out ways to lower their costs of controlling for weeds and take independent action.

Bootstrapping it

The "Bootstrapping it" group reported moderate amounts of weed control despite being highly constrained. They were concerned about weeds and worked to control weeds even though they have limited time and money. This group was the most connected with their neighbors, and believed their neighbors expected them to control for weeds. This group had the largest average parcel size, 718 acres, and largest median parcel size, 40 acres. The attributes of this group suggest that some material constraints may be overcome though social engagement/ ties.

Management implications

The "Bootstrapping it" group could also be another prime group to target because results suggest they are motivated to control and would likely use take advantage of additional resources. The "Bootstrapping it" group is the most willing of any group to meet with an extension professional and to apply for a government grant. Connecting members of this group to support, whether that be an extension agent or government grant, would likely increase their engagement. Members of this group would also be great candidates to reach out to their neighbors and encourage them to control for weeds.

Can't do much

While the "Can't do much" group is unsatisfied with weed control in their area, they reported the lowest amount of time and money, and do not engage in much control. This was the smallest group out of the five (15.4%), and this group's average parcel size was 329 acres. They also had low confidence in their ability to control for weeds. Socially they did not think their neighbors are controlling for weeds, or that their neighbors expect them to control for weeds.

Management implications

I believe engaging this group may be difficult because they need both material support and social impetus. However, they are generally willing to meet with an extension agent which could be the most promising pathway to both meet their needs and instill the social norm for controlling.

Unconcerned

The "Unconcerned" group are not concerned about weeds and they are satisfied with weed control in their area. This group has a moderate amount of resources to control; however, they engage in the least amount of weed control.

Management implications

I believe this group may be the most difficult to encourage, because they do not see weeds a problem. While they are somewhat willing to take independent action, they not interested in meeting with an extension agent, and unwilling to apply for a government grant. This is a group that may be more motivated by social sanctions than direct outreach, if others are controlling in an area this group may become more aware that weeds are a community concern and start to take action.

General management implications

When developing outreach, I saw two different pathways for engaging landowners. First, a manager may have a group of people they are trying to engage, or second, a tool they are trying to promote. My results could inform either way for engaging landowners in weed control. If a land manager is trying to engage a certain type of landowner my results demonstrate how outreach needs to be tailored to that group. For example, if an extension agent wanted to engage the “Doing all they can,” a group that *is* interested in engaging in more weed control, they are most willing to spend time pulling weeds or using herbicides. While this group reports monetary constraints, only about a third of this group (36.5 percent) are willing or very willing to apply to government grants. So, while it seems intuitive to lower the costs of weed control through grants, this group may not be motivated by outreach promoting government grants. Instead figuring out other ways to lower the cost or individual actions, such as group spraying days that would save the landowner time, could encourage the group to do more weed control. By tailoring their outreach managers can pinpoint who they want to engage and create specified messages that will be most effective for that group.

However, a tool that does not work for one group does not mean it is an ineffective tool. For example, government grants are an ineffective tool, they just do not appeal to all landowners. Land managers may have a tool they want to promote, which may engage only certain types of landowners. Even though “Doing all they can” was not interested in applying for government grants, the majority of both the “Bootstrapping it” group (66.9%) and the “Can’t do much” group (55.8%), were interested in grants. Both groups had monetary constraints, and government grants may allow them to engage in more weed control.

These results show there is no blanket solution to weed control, instead a variety of tools can be used to engage a variety of landowners. Segmenting the population allows managers to see what messages are appealing to different groups, triage and target landowners they are trying to reach. Mangers can use clusters to tailor their messaging by picking a group they want to engage, and tailoring outreach messages to that group. Or if managers are trying to promote a certain tool, they can assess what groups are more likely to adopt that tool. Either approach allows managers to specific their outreach, and, instead of a broad message that appeals to no one, create messages that work toward specific objectives.

Conclusion

Landowners are concerned about the effects of weeds and believe both that their actions, both individual and with neighboring landowners, can be successful. However, they face both individual constraints and collective constrains. Many landowners simply do not have the material resources to engage in effective weed control. In addition, most landowners do not think others around them are taking steps to control. This suggests managers need to address both material and social aspects of weed control. By segmenting the population, managers can tailor outreach that both relieves some material constraints, such as government grants, and promotes the most effective social messaging, such as social norms, to certain segments of the landowner population. To achieve landscape-wide weed control, one or two messages about weeds will not suffice instead land managers need to think strategically about the people they want to engage, and then tailor messages to that group. There is no "average landowner," and, rather than a single message or tactic, weed control outreach needs to instead speak to the variety of landowners on the landscape. This may mean crafting many different types of messages that each speak to a different to different types of landowners. By diversifying messages managers can engage more landowners and start to build landscape-wide engagement. The collective nature of weeds and the effects on individual behaviors are detailed and discussed in Chapters 2 and 3.

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Chapter 2

The collective interest behind independent behavior: Quantifying a cross-boundary model of invasive species control in a complex ownership mosaic

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Abstract

Weeds reduce the biodiversity and productivity of agricultural systems. Weeds are challenging to control because their effective dispersal mechanisms enable cross-boundary colonization, and so managers must engage diverse groups of private landowners. Researchers have recognized weed control is a collective action problem, but there is little research quantifying the role of collective factors on an individual's decision to control. To fully understand the motivations behind independent weed control, we initiated a study to quantitatively assess the relationship between collective interest variables and individual landowners' willingness to engage in weed control behaviors. We identified the Collective Interest Model as a way to understand the influence of collective factors on an individual's decision to control for weeds, while holding individual factors constant. We surveyed Montana landowners (n=4,500), and analyzed results using ordinarily least squares regression. We found collective factors, such as an injunctive norm and the belief that weeds are a cross boundary problem, were significantly correlated with willingness to engage in three different weed control behaviors. This suggests if weed control outreach explicitly promotes collective messages, it may be able to more effectively engage landowners.

Introduction

The spread of invasive species (IS) is one of the leading drivers of global environmental change (Simberloff et al., 2013). Nearly half (42%) of threatened or endangered species in the United

States (US) are at-risk primarily because of IS, and their economic impact in the country has been estimated at $120 billion (Pimentel et al., 2005). Invasive terrestrial plants that interfere with human activities constitute a specific type of IS (Zimdahl, 2018), hereafter referred to as "weeds." Weeds outcompete native plants and alter host ecosystems with adaptive strategies that allow them to quickly spread and make them challenging to control (Baker, 1974). Once weeds have propagated, both natural and human-mediated processes can contribute to dispersal, often across jurisdictional and ownership boundaries (Baker, 1974; Fiege, 2005). Thus, adequate weed control often requires proactive behaviors by diverse land managers, especially in systems where private landownership is common. In such places, the individual decisions of private landowners aggregate to determine landscape-wide ecological outcomes. The need for coordinated efforts across property boundaries to control for weeds creates a collective action problem, yet collective action research on weed control behavior is in its infancy.

To adequately understand and effectively encourage weed control by private landowners, human dimensions studies have long focused on landowner's attitudes, (García-Llorente, Martín-López, González, Alcorlo, & Montes, 2008; Selge, Fischer, & van der Wal, 2011; Sheley, Jacobs, Floyd, & Floyd, 2010). Researchers have found that an individual's attitude towards a species affects what weed control management they deem acceptable (Fischer & Charnley, 2012; N. A. Marshall et al., 2011). However, engaging in weed control behavior, like most behaviors, is not simply a determinant of attitudes, but rather a product of several interrelated contextual and individual factors such as material resources. This has been established generally by social psychologists (Fishbien & Ajzen 2010) and specifically within invasive control literature (Kalnicky et al., 2014). With regard to weeds, landowners tend to have negative attitudes, but to fully understand landowners' behavior, research must consider a more inclusive suite of influential factors (Aslan et al., 2009).

Studies of landowners' weed control behavior have found that time, money, and knowledge are often major constraints (Sheley et al., 2010; Yung et al., 2015). Other landowners are limited by their knowledge about how weeds spread or are unable to identify weeds (Fischer & Charnley, 2012; Sheley et al., 2010). Such lack of information or misinformation can exacerbate weed invasions because landowner behaviors may inadvertently exacerbate invasion (Aslan et al., 2009). However, while these individual constraints help explain some variation in landowner weed control behaviors, the collective action aspects of the problem have been largely ignored in the literature. In systems where land decisions are divided among many actors, as is the case for landscapes with substantial private landownership, weeds are a cross-boundary problem where weed control cannot be explained by individual factors alone.

Thus, weed control on private land settings constitutes a collective action problem in which landowners act independently, yet the behaviors of landowners are interrelated, and success depends on broad participation. In collective action problems (a particular type of social dilemma), the behavior of one actor affects other actors without their agreement, negative externalities without consent (Kollock, 1998). With respect to IS, a landowner who does not control for weeds is contributing to their spread across property boundaries and negatively impacting other nearby landowners. This represents a classic collective action problem where all actors may benefit from a public good, if provisioned, but a single actor is less likely to contribute if those around her do not contribute themselves (Chong, 1991). In some collective action problems, particularly within large groups, individual actors may feel that their actions are insignificant, and chose not to act (Finkle & Muller, 1998). Such non-contributors may still enjoy the benefits of others' contributions without contributing herself, becoming a "free-rider," and possibly making collective action costlier for everyone else. When free-riders become too common they undermine others' collective efforts to provide a public good. These social dynamics have been well documented in natural resource contexts (Ostrom, 1990), as well as other fields such as political science (Chong, 1991).

Some IS researchers have begun to empirically explore how the cross-boundary nature of weeds affects landowners' weed control behaviors. In fact, recent studies of weed control have concluded that the collective nature of weed control is one of the most prominent factors influencing landowners (Epanchin-Niell et al., 2010; G. R. Marshall et al., 2016; Niemiec et al., 2016; Sindel, Berney, Coleman, Marshall, & Reeve, 2013; Yung et al., 2015). Landowners often see the collective nature of weed control as a constraint on their ability to effectively control weeds. For example, Yung et al. (2015) found that many landowners believed their weed control efforts were undermined when seeds dispersed from neighboring properties, and Niemiec et al. (2016) observed people who were discouraged from controlling weeds because they perceived a lack of participation or coordination among neighboring landowners. Other studies have found that tensions among landowners may limit control. For example, older landowners frequently do not trust that newer, or "amenity" landowners can identify weeds or implement effective control, and believed that the new landowners undermined their efforts to control (Epanchin-Niell & Wilen, 2015; S. Graham, 2013; Klepeis et al., 2009; Yung & Belsky, 2007).

In other instances, collective factors have been found to motivate weed control. Landowners have reported they controlled for weeds to be a good neighbor, and they expected others to reciprocate (Yung & Belsky, 2007; Yung et al., 2015; Niemiec et al., 2016; Kelpies et al., 2009; Marshall et al., 2016). Minato et al. (2010) described a small community that viewed weed control as every landowner's responsibility and enforced this norm through social sanctions such as gossiping about landowners who failed to comply. Some communities have used the social and material benefits provided by a collaborative weed control group to motivate landowners to control (Hershdorfer et al., 2007; Graham & Rogers, 2017). These groups lowered the cost of weed control by creating a space to share knowledge, and working together on one property at a time (Graham & Rogers, 2017). These groups also provided social benefits by reducing the stigma of having weeds, and building both a sense of community and social capital (Graham & Rogers, 2017; McKiernan, 2017; Reid et al., 2009).

Theories and observations of collective action problems outside of natural resources field provide insights which may help explain how collective forces influence weed control behaviors. Political science research, for example, often assumes an actor will only contribute if she recognizes the problem is indeed collective, her grievance is high enough, and the group has a chance of being successful (Finkel & Muller 1998). Economic games have demonstrated that actors are frequently motivated to act collectively to maintain reputation and social standing (Milinski et al., 2002; Nowak & Sigmund, 2005; Chong, 1991). Ostrom (1990), an economist and political scientist who often worked on natural resource issues, concluded that actors are more likely to contribute to a collective institution when they have had face-to-face interactions with other members of the community. The importance of these factors to other collective action problems suggests they may be applicable to weed control as well.

Although a nascent field of research, initial studies of the collective nature of weed control suggest collective factors can be critical deterrents or motivations in landowner decisions to control for weeds. Still, the extant research on the collective nature of weed control are generally qualitative and disproportionately focused on collective behaviors, such as actions organized by collaborative weed groups (Graham, 2013; Graham & Rogers, 2017; Marshall et al., 2016; Hershdorfer et al., 2007;). Importantly, however, the decision to control for weeds on private land is often made autonomously, and collective responses by weed control groups are the exception rather than the norm (Graham et al., in review). Factors driving participation in collective behaviors or collaborative groups may or may not translate to individual landowner behaviors.

Research Purpose

We sought to quantify the role of collective factors in determining landowners' independent weed control behaviors (i.e., not collective behaviors). We hypothesized that weed control by private landowners is a collective action problem because, holding individual factors constant, collective factors would explain significant variation in weed control behaviors. By parsing the role of collective forces from individual factors, we sought to enrich our understanding of individual landowners' utility calculus when choosing to control for weeds, thus contributing to future research and efforts seeking to promote weed control efforts on private lands.

Collective Interest Model

To accomplish these research goals and test our hypothesis we used the Collective Interest Model (CIM; Eq. 1). The CIM was first developed to explain political protest behavior and has since been used to explore behaviors in a variety of collective action situations (Finkel & Muller, 1998; Lubell, 2002; Yau, 2011). The CIM model allows associations between behaviors of interest with: (1) an individual's value of the public goods provided by the action, (2) the extent to which an individual thinks his or her personal actions can affect the provisioning of the public good, and (3) the extent to which an individual believes others will contribute to the public good (Finkel & Muller, 1998). The CIM assumes individuals will be influenced by the selective costs and benefits of engaging in behavior, which allows for the inclusion of attitudes, norms, knowledge, values, and other factors found in both the weed control and broader literatures. The model recognizes the temptation to free-ride, but Finkel and Muller (1998) assume actors will contribute more than expected because they have bounded rationality and often overestimate the effect of their contributions to a public good (Finkel & Muller, 1998).

$$EV\ (weed\ control\ behaviors) = [(p_i + p_g) * V] + B - C$$

Eq. 1. Collective interest model

The CIM was used in one study to explain collaborative IS control (Niemiec et al., 2016). The study was located in the Puna district of Hawai'i, where albizia trees, F*alcataria moluccana*, were dropping branches after a recent hurricane, causing dramatic and costly damage to cars and homes. Niemiec et al. (2016) measured weed control "activism" behaviors such as teaching a neighbor how to remove albizia or removing albizia from a public space. Results proved the CIM successfully explained behavior, however Niemiec et al.'s (2016) results are contextually specific, and it remains unclear if their findings are relevant for independent weed control behaviors.

Study Site

The state of Montana, USA provided an ideal context to study landowners' weed control because the majority of land is privately owned and affected by weeds. Over 60 percent of the land is privately owned, and weeds were identified as a problem in the state as early as the 1890s when homesteaders began to farm the area (Fiege, 2005). Currently, Montana has 17 high priority noxious weed species that are "widespread in many counties," and 20 other less abundant noxious weeds species (Montana Department of Agriculture, 2018).

Methods

We collected data using a mail-back questionnaire sent to Montana private landowners. Our sampling frame included non-public landowners owning between .5 and 6,000 acres of land outside of incorporated city limits. We set these parameters to focus our study on smaller landowners because small landowners collectively own a large portion of the land base and have diverse landownership goals. Smaller owners own land for diverse reasons, making it difficult to pinpoint singular motivations behind their land management behaviors. We regionally stratified the sample (i.e., western, central, and eastern regions; Figure 1) to ensure adequate representation of landowner perspectives across the state. We drew an initial sample of 4,500 landowners (1,500 per region) using the Montana cadastral data (Base Map Service Center Montana State Library, 2017). We pretested the questionnaire with graduate students and faculty at the University of Montana, employees of the Montana Department of Natural Resource and Conservation, and extension professionals. We administered the survey using a tailored design method (Dillman et al., 2014) that included a cover letter and questionnaire, a reminder postcard, and two replacement questionnaires to non-respondents with each mailing spaced approximately two weeks apart. All research methods were approved by the University of Montana Institutional Review Board prior to administration.

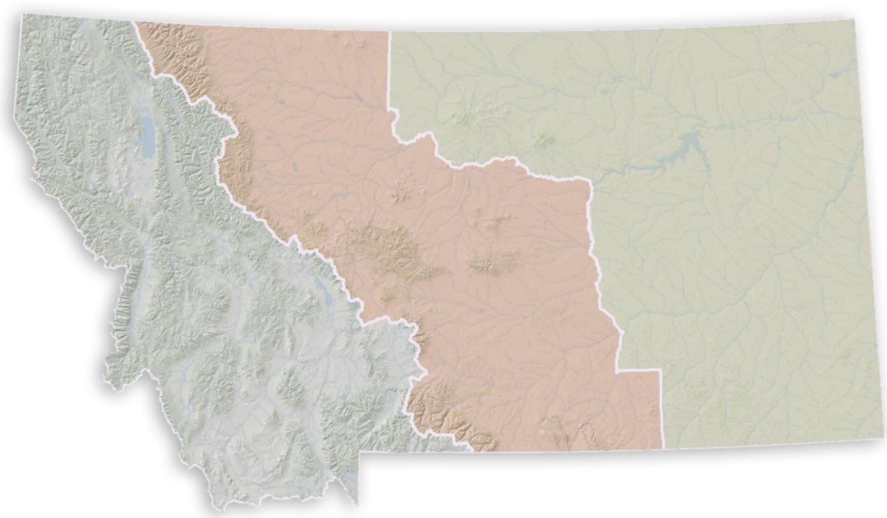

Figure 1. Map of Montana with the three regions used in survey implementation

Adapted Collective Interest Model

Our adaption of the CIM posited that individuals will be more willing to engage in weed control if (1) they believe their weed control actions will be successful, (2) they believe those around them are also controlling, and (3) the group's actions will be successful, (4) they value the outcome of the collective action, in this case a weed free environment, and (5) if actions are not too costly. Below we describe how we operationalized each of these factors, often adapting extant measures from previous research on collective action problems (Finkel & Muller 1998; Lubell, 2007; Niemiec et al., 2016).

Dependent Variables

Our dependent variables were: willingness to (1) work with an extension professional to develop a weed control plan, (2) use herbicides to control weeds, (3) release bio-control (i.e., insects) to control weeds, and (4) spend time pulling weeds on your property (Table 1). We conceptualized willingness as a behavioral intention, which is a precursor to the behavior (Ajzen & Fishbein, 2005; Lubell, 2007). We chose behavioral intentions as dependent variables because although they are not adequate substitutes for behaviors, we believed they were less problematic than self-reported behaviors. Self-reported weed control behaviors can be particularly problematic because landowners are legally responsible for controlling noxious weeds (MCA Section 7-22-2116), and this may lead to overstatements. All dependent variables were measured on a five-point Likert scale from Very Unwilling to Very Willing (Table 1).

Independent Variables

We drew our independent variables from literature pertaining to invasive species control on private land, and other collective action research. All independent variables were measured on five-point scales, with the exception of norms and network centrality variables which were dichotomous, yes/no variables (Table 1).

Collective Interest Variables

We included several collective interest variables, attempting to measure multiple possible collective action dynamics. Specific item wordings, and descriptive statistics are included in Table 1. Group efficacy (p_g) was conceptualized as whether an individual believes that collective contribution to weed control will be effective. In addition to effectiveness, the CIM assumes that it is rational to contribute to the public good only if you believe others in the group will also contribute. We broke group efficacy up into two categories: expected reciprocity and generalized group efficacy (adapted from Niemiec et al. 2016). We included a measure of expected reciprocity because we predicted that landowners who believe their actions will inspire others would be more likely to believe the group can achieve a weed-free environment (Niemiec et al. 2016, Cialdini 2009). To measure generalized group efficacy, we asked landowners' if they felt that together with their neighboring property owners they could effectively control for weeds in their area (Table 1). To evaluate a landowner's perception of weed control in their area in general, we measured area wide satisfaction (V).

To measure individuals' ease of gaining information about weed control we asked whether or not respondents have discussed weed control with friends and family (adapted from Lubell, 2007). We included behavioral control beliefs about money, time and knowledge of how to control. We included a Sense of Community scale, which measured if a landowner felt supported by their community, and that they were an effective agent in their community (adapted from Absher, Vaske, & Lyon, 2013).

Individual Variables

Several measures were included to measure landowners' perceptions that collective action will be successful. Personal efficacy (p_i) measures whether individual behavior will contribute to the collective outcome. To measure this, we asked landowners they felt their personal actions could help control for weeds on their property (Table 1). We measured individuals' valuation of the individual benefit (V), a weed-free environment, by measuring individual concern of weeds on their property via a battery of related questions (Table 1).

Participating in weed control may require material costs (C), and provide, social and psychological benefits (B). We asked demographic questions to determine how easily landowners can absorb the costs (C) of completing control behavior. These include age, income, education level, acreage and gender (Lubell et al., 2007; Niemiec et al., 2016). To measure psychological benefits of engaging in weed control we asked two questions from the New Environmental Paradigm (Dunlap & Van Liere, 1978; Lubell, 2002). We included a measure of injunctive and descriptive norms regarding weed control to measure the potential social benefits of engaging in weed control (Table 1; Niemiec et al., 2016).

Table 1. Variables and scales for the survey organized using the collective interest model

	Variable	CIM designation	Scale
Collective			
	Cross-boundary belief	P_g	5-point Strongly disagree-Strongly agree
	Reciprocity- notice or hear	P_g	5-point Strongly disagree-Strongly agree
	Reciprocity-motivate to act	P_g	5-point Strongly disagree-Strongly agree
	Group efficacy	P_g	5-point Strongly disagree-Strongly agree
	Area wide satisfaction	V	5-point Very unsatisfied to Very satisfied
	Network centrality-ask opinion	C/B	2-point Y/N
	Network centrality- influence opinion	C/B	2-point Y/N
	Descriptive norm	C/B	5 point Strongly disagree-Strongly agree
	Injunctive norm	C/B	5-point Strongly disagree-Strongly agree
	Sense of Community	C/B	
Individual			
	Personal efficacy	P_i	5-point Strongly disagree-Strongly agree
	Concern	V	
	Weeds decrease enjoyment		5-point Strongly disagree-Strongly agree
	Weeds decrease the economic value		5-point Strongly disagree-Strongly agree
	Weeds decrease the productivity		5-point Strongly disagree-Strongly agree
	Weeds negatively impact the appearance		5-point Strongly disagree-Strongly agree
	Weeds limit my ability to use		5-point Strongly disagree-Strongly agree
	Money	C/B	5-point Strongly disagree-Strongly agree
	Time		5-point Strongly disagree-Strongly agree
	Confidence in ability to control	C/B	5-point Strongly disagree-Strongly agree
	Confidence in ability to identity weeds		
	Trust the government to control for weeds	C/B	5-point Strongly disagree-Strongly agree
	Age	C/B	Open response
	Biocentric environmental belief	C/B	5-point Strongly disagree-Strongly agree
	Anthropocentric Environmental belief	C/B	5-point Strongly disagree-Strongly agree
	Education	C/B	5 Categories: Grade school, High school/ GED, Some college, College graduate, Post graduate
	Income	C/B	9 Categories: >$9,999, $10,00-1$9,999, $20,000-$39,999, $40,000-$59,999, $60,000-$79,999, $80,000-$99,999, $100,000-$119,999, $120,000-$139,999, $140,000->$140,000
	Acreage	C/B	Open response
	Gender	C/B	Male/ Female

Before analysis, we created a composite "concern" variable by averaging responses from five items focused on different ways weeds could negatively affect landowners' properties (Table 2). We also created a composite "sense of community" variable by averaging the responses from four items regarding community effectiveness in solving problems, and to what degree landowners felt they could be effective agents in their community (Absher et al., 2013). We measured scale reliability of these two composite independent variables using Cronbach alpha test with a 0.65 cut-off (Vaske, 2008).

Analysis

To test our hypotheses, we conducted an Ordinary Least Squares Regression, common in CIM analyses (Lubell et al., 2007; Yau, 2011; Niemiec, 2016). The linear additive function form of OLS regression does not represent the multiplicative relationships in the CIM so the equation is often adjusted to:

$$EV\ (weed\ control\ behaviors) = p_i + p_g + V + B - C \qquad \text{(Eq. 2)}$$

which allows for the simplest interpretation of significant variables (Lubell et al., 2007). We used this form of the CIM for its simplicity of interpretation, and consistency with existing literature. To test OLS assumptions we reviewed descriptive statistics of each variable to confirm normality, linear relationships with dependent variables, and homoscedasticity. To account for sampling design, we weighted responses according to methods outlined by Vaske (2008). We performed an OLS regression for each of the four dependent variables in IMB SPSS Statistics 24. We used Variance of Inflation Factor (VIF) procedures to determine there was no multi-collinearity, and P-P plots to determine if residuals were normally distributed (Vaske, 2008).

As a non-response check, we conducted independent t-tests comparing respondents to non-respondents across several variables available in the MT cadastral dataset, including land value, total value, building value, size, farm acres, grazing acres, forest acres, fallow acres and irrigated acres, wild hay acres and non-quality acres. We used a p-value of .05 to detect significant differences between respondents and non-respondents.

Results

Initial sample size was reduced to 4,424 after we removed duplicate and incorrect addresses. Respondents totaled 1,327 for a response rate of 30 percent. Respondents were generally well educated (51% of landowners reported having a college degree or higher), older (average age was 64 years), and male (69%), with high income (34% reported over $100,000 of annual household income), consistent with landowner populations in the US. Descriptive statistics for all variables are shown in Table 2, results shown are weighted to represent statewide results.

Residual plots indicated normal distributions for three of dependent variables. However, using the P-P plot we determined that data for the dependent variable "*Willingness to pull weeds on your property"* had non-normally distributed residuals and excluded this measure from further analysis. We determined there was no multicollinearity using Variance of Inflation Factor (VIF) procedures. We found no differences between respondents and non-respondents in our sample with two minor exceptions: respondents had slightly, but statistically significantly more wild hay acres and non-quality acres. Across all other variables, respondents were not significantly different from non-respondents, so we assumed our respondents were representative of the broader population.

The majority of landowners agreed or strongly agreed that weeds decreased their enjoyment of their property (82%), and that weeds limited their ability to use their property in the ways they wanted (81%). Although most landowners were concerned about weeds, many reported limited resources for control efforts. For example, only about half felt they had enough time (50%) or money (53%) to control for weeds on their property.

Table. 2 Survey constructs and descriptive results from survey items

Variable	Survey	Mean	Standard Deviation	Cronbach Alpha
Dependent variable 1	Work with an extension professional to develop a weed control plan for your property	3.72	.926	
Dependent variable 2	Use herbicides to control weeds	3.95	.991	
Dependent variable 3	Release bio-control (Insects) to control weeds	3.727	1.01	
Dependent variable 4	Spend time pulling weeds from your property	3.83	.992	
Group efficacy	Together, neighboring property owners and I can effectively control weeds in our area	3.85	.884	
Satisfaction	How satisfied or dissatisfied are you with the current efforts to control weeds in your area?	2.98	.983	
Network centricity- ask opinion	Has anyone ever asked you for your opinion on weed control?	1.28	.449	
Network centricity- influence opinion	Has anyone ever tried to influence your opinion on weed control?	1.27	.445	
Injunctive norm	Do most people in your area believe you should be taking steps to control weeds on your property?	1.54	.499	
Descriptive norm	Do you believe most people in your area are taking actions to control weeds on their properties?	1.44	.497	
Sense of Community		3.34	.77	.843
	I feel a strong sense of community with my neighbors	3.52	.932	
	If there is a problem in my area, people here get it solved	3.47	.913	
	I have an influence over what this community is like	3.16	.953	
	I often take an active role in solving area problems	3.2	.926	
Personal efficacy	My personal actions can help control weeds on my property	4.11	.773	
Concern		3.93	.83	.907
	Weeds decrease my enjoyment of my property	4.09	.903	
	Weeds decrease the economic value of my property	4.03	.909	
	Weeds decrease the productivity of my property	3.91	.994	
	Weeds negatively impact the appearance of my property	3.46	.896	
	Weeds limit my ability to use my property in the ways I want	3.46	1.108	

Money	I have enough money to control weeds on my property	3.28	1.122
Time	I have enough time to control weeds on my property	3.18	1.116
Confidence in ability to control	I am confident in my ability to identify weeds	3.48	1.086
Confidence in identify weeds	I am confident I know how to effectively control weeds on my property	3.43	1.077
Trust in government	Trust the government to control for weeds	2.17	.958
Age	Age	64.32	12.88
Biocentric environmental belief	The balance of nature is delicate and easily upset	3.77	1.019
Anthropocentric environmental belief	Economic growth should be given priority, even if the environment suffers	2.25	1.052
Acreage	Acreage	Median=20	
Education	Education	Mode=Some College	
Income	Income	Mode= $60,000-$79,000	
Gender	Gender	Male 63.5% Female 28.8%	

We found collective factors were significant for each behavior, although results varied across behaviors. *Working with an extension professional* had three significant collective factors, using herbicides had two, and releasing bio-control had one. Each behavior also had a unique suite of significant individual variables (Table 3).

Three collective measures were significant and positively correlated with willingness to *work with an extension professional*: knowledge weed control was a collective problem, group efficacy, and sense of community. Three individual beliefs were significant and negatively correlated having enough money, confidence in weed control ability, and the anthropocentric environmental belief. Income was positively correlated, and the strongest predictor (Table 3).

Two collective measures were significant and positively correlated for *willingness to use herbicides*: knowledge weed control was a collective problem and the injunctive social norm. Two individual factors were significant and negatively correlated: concern about weeds, and the biocentric environmental. Income was once again positively correlated and the strongest predictor of willingness to use herbicides (Table 3).

Network centrality was the sole collective factor that was significant and positively correlated with willingness to release biocontrol. Two individual factors were positively correlated: concern about weeds and education. Two individual beliefs were significant and negatively correlated: having enough money, and the anthropocentric environmental belief (Table 3).

Table 3. Selected independent variables from the collective interest model predicting weed control behaviors, based on an Ordinary Least Squares model. Cell entries are unstandardized coefficients and standard errors

	Variable	Willingness to work with an Extension Agent		Willingness to use Herbicides		Willingness to use Biocontrol	
R^2		.201		.248		.197	
		Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
	Constant	2.463***	.513	.747	.502	1.360**	.532
Collective	Cross-boundary belief	.277***	.081	.281***	.080	n.s.	
	Group efficacy	.116*	.067	n.s.		n.s.	
	Sense of Community	.118*	.068	.176**	.067	n.s.	
	Reciprocity	n.s.		n.s.		.111*	.065
	Network centrality	n.s.		n.s.		.276**	.118
	Injunctive norm	.17*	.104	.178*	.062	n.s.	
Individual	Anthropocentric environmental belief	-.086*	.049	n.s.		-.108**	.051
	Biocentric environmental belief	n.s.		-.103**	.050	n.s.	
	Concern	n.s.		.169**	.061	.233***	.065
	Education	n.s.		n.s.		.117**	.046
	I have enough money	-.111**	.054	n.s.		-.129**	.056
	Confidence to control	-.163	.063	n.s.		n.s.	
	Income	.326*	.171	.369**	.167	n.s.	

Discussion

Landowners' decisions to control for weeds are not simply individual and isolated actions, but instead constitute participation in a cross-boundary, or collective action problem. To parse out the motivations and constraints for engaging in weed control, past research has explored which attitudes and individual resources influence these landowner decisions (Sheley et al., 1996). Additionally, research has examined how collective factors influence a landowner's decision to engage in collaborative control (Graham & Rogers, 2017). However, little has been done to quantify the importance of the collective constraints and motivations on individuals' specific weed control behaviors. While qualitative research has suggested the importance of collective factors, we established quantitative empirical evidence of their association with independent weed control behaviors.

Our results demonstrated that collective factors were significantly related to individuals' willingness to take independent action to control for weeds on their private property. Collective factors were correlated with each weed control behavior, indicating their importance for a variety of weed control interventions. The significance of collective factors in our large study site, and broad context of weed control show they cannot be ignored when trying to understand landowner weed control decisions and may be provide useful insight to those attempting to encourage more robust control measures on private lands.

We found collective factors were not monolithic, but that different behaviors were driven by different collective factors. For instance, group efficacy, sense of community and reciprocity were positively correlated with willingness to work with an extension agent. This suggested that landowners who saw themselves in a community that takes action to control weeds, and solve other problems, were more willing to go to an extension agent. In contrast, recognizing weeds were a cross boundary problem and injunctive norm beliefs were positively correlated with willingness to use herbicides. The significance of the social norm suggested landowners who felt a sense of obligation to those around them were more willing to take action. These results indicated subtle differences in motivations behind different behaviors that may have important implication for designing outreach.

As with collective factors, we found that each weed control behavior was correlated with a unique suite individual of factors. For instance, education was only significantly related to willingness to release biocontrol, possibly indicating the unique knowledge resources needed to implement or accept biocontrol. Individual values were also only correlated with some behaviors. For example, our measure of anthropocentric environmental belief was negatively correlated with landowners' willingness to work with an extension professional, and release bio-control. This is consistent with other findings in the weed control literature such as Niemiec et al.'s (2016) finding that different albizia control behaviors were correlated with unique costs and benefits.

Our findings that behaviors were correlated with unique factors suggested that the most impactful outreach may require managers to identify the specific behavior they are interested in changing, and tailor their message to induce such change (McKenzie-Mohr et al., 2011). Our results indicated messages promoting certain collective factors, such as highlighting the injunctive norm, may motivate landowners to take certain types of weed control action, but not others. Effective weed-control is also regionally and temporally specific, so messages to encourage weed control managers must likely be precise in the language they use to have the desired effect. If landowners concerned about environmental impacts are unwilling to use herbicides, educational material about herbicide effectiveness at enhancing ecosystem function may not alter behavior. In fact, messages about herbicide efficacy may reinforce existing negative attitudes and undermine willingness to use them. Thus, managers must not only create messages specific to the behavior they wish to modify, but also target a certain group of landowners for whom particular messages will be relevant.

In this vein, it is important to note that Montana landowners were already very concerned about the impact of weeds, so messaging to encourage weed control must likely extend beyond simply raising additional awareness. Messaging campaigns focused on raising awareness have been deemed ineffective in many settings, but especially when awareness is already high (Amel et al., 2017). In Montana, we found a strong majority of landowners (81.6%) were concerned about the impacts of weeds on their property. Rather than investing in efforts to continue raising awareness, a more effective approach might be to emphasize collective aspects of this issue, even using the same communication modes. For instance, billboards that celebrate local landowners who are doing a good job controlling could serve to elevate both injunctive and descriptive norms around weed control and inspire more widespread control. Or, providing participating landowners with signs to post on their properties acknowledging the actions they are taking could foster a greater awareness of the expectation of controlling for weeds (Graham & Rogers, 2017). Signs for participating landowners may be particularly effective because, as Milinski et al. (2002) found, maintaining a good reputation is an important motivating factor for engaging in cooperative behavior in economic games.

Collective factor messages could also be incorporated into other outreach formats. For example, workshops that teach landowners different control methods could also serve to reinforce social norms surrounding weed control and explicitly talk about the cross-boundary nature of weeds. Extensive research has demonstrated that face-to-face interactions increase participants' willingness to engage in collective behavior (Ostrom, 1990). Workshops are a platform where landowners can interact in this personal manner; in these settings, facilitated discussions around the difficulties of weed control may help create solidarity among landowners and recognition that the problem extends beyond property boundaries, both of which may inspire increased weed control behavior (Graham & Rogers, 2017). The collective aspects of weed control may not need to be the central focus of the workshop, but explicitly discussing them could motivate landowners to control.

The importance of collective factors suggests the need to both incorporate and test the effectiveness of novel weed control outreach methods that explicitly highlight collective elements of weed control. Our results could set the stage for a targeted outreach experiments, where some landowners are given messages that appeal to the collective nature of weeds, and others are given messages focuses on individual resources. Testing the effectiveness of collective factors could open the door to developing a host of novel weed control outreach methods. Longitudinal studies could examine if these types of messages foster sustained weed control efforts. As the literature around the collective nature of weed control builds, it has become increasingly obvious that collective messages should be incorporated into weed control outreach, although details regarding their effectiveness remain elusive.

While our study illuminates the importance of collective factors in weed control, our results may be limited by our cross-sectional survey which allowed us to correlate weed control with collective factors, but not determine causality. We also addressed weeds generally, and our results may not be applicable to very specific weed species. Due to limited resources we were not able to conduct a more robust non-response check, so it remains possible that our respondents may be more apt to participate in collective action than non-respondents. Our sample consisted of Montana landowners, and due to the state's long history with weeds and specific regulatory context, they may have perspectives on weed control inapplicable to landowners in other areas.

Conclusion

There may be profound opportunity for outreach professionals to inspire weed control by engaging landowners around the collective nature of the weed problem. Our results showed landowners were both concerned about weeds on their property and aware weed control is a social dilemma, suggesting there is little room to increase behavior by targeting these variables. We found that collective factors were significantly correlated to willingness to engage in three different weed control behaviors, indicating their importance to weed control broadly. Incorporating collective messages into weed control outreach could prove to be a fruitful opportunity to reframe weed control as a moral good for the community, which may engage landowners who see the problem as unsolvable, although further experimental research is needed. While many landowners struggle to sustain motivation for weed control, critically deploying collective motivations for weed control offers a new array of tools for land managers to try.

Clear communication is critical as conservation efforts move from public protected areas to private lands, because land managers will have to effectively communicate with a diverse group of landowners. Private landowners make many land management decisions autonomously, but they are likely influenced by what others are doing around them (Cialdini, 2009). By looking at both the collective and individual driving factors for these decisions managers can help build coordinated efforts across ownership boundaries. Our results suggest the CIM is a potential tool to look at a host of cross-boundary environmental issues that take place on private land. Private land conservation is critical to creating wildlife corridors, stream buffers and other important land management changes. Our study shows that while these maybe individual decisions by landowners address cross boundary problems, collective variables play a significant role in an individual's calculus.

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Chapter 3

Reframing Weed Control as a Public Goods Problem

Weeds are inherently a cross-boundary problem where landowner management decisions can create negative externalities for neighboring landowners (Kollock, 1998) Thus, weed control is a collective action social dilemma, as I have detailed in Chapters 1 and 2 of this thesis. Studies of weed control have acknowledged the importance of collective factors, such as trust, reciprocity, and social norms, in determining landowner weed control behaviors (Epanchin-Niell et al., 2010; Graham, 2013; Yung, Chandler, & Haverhals, 2015; Aslan 2009). While natural resource collective action issues are often classified as common pool resources (CPR), other fields such as political science and economics have developed differentiated theories and rules around multiple types of CPR problems, and other collective action problems more generally, such as public good problems (Kollock, 1998; Oliver, 1993; Sandler, 2015; Schelling, 1978; Leider et al., 2017). Especially in the weed control literature, this oversimplification of collective action problems suggests that many authors are either unclear about what type of collective action problem weeds constitute, or simply adopt a CPR framework without critical examination of the dynamics of the collective action problem (Stallman & James, 2015; Graham et al., in review). In this Chapter I review the history of collective action problems to describe and differentiate CPR from public good problems before critically examining the collective action nature of weed control. I discuss implications of past misclassification of weed control as CPR problems and suggest how weed control research and policy could benefit from more robust integration of collective action theory. While Graham et al. (in review; a paper to which I have contributed) initially observed this misclassification, here I aim to more deeply explore the distinctions between CPR and public goods and discuss implications for their application to understanding landowner weed control behavior.

History of Collective Action

A common basis of collective action problems was demonstrated in the "prisoners' dilemma," a thought experiment created by economists Flood and Dresher (1950). In their scenario, two suspects accused of a crime are interviewed in separate cells. The suspects each have two options: either (a) deny, or (b) confess. Mutual denials will result in moderate punishment, while mutual confessions will earn both prisoners slightly worse sentences. However, if one prisoner confesses while the other denies, the confessor will receive a light sentence and the denier will receive a severe punishment. While the optimal outcome is for both to deny, the Nash equilibrium is for both to confess, either in hopes of earning the lightest sentence or to defend against confession by the other. A Nash equilibrium is a stable state in a social interaction where no person can gain by changing their strategy as long as all other participants remain unchanged (Nash, 1950). This thought experiment (and subsequent empirical evidence) demonstrated that people often make suboptimal decisions for the group and themselves in an effort to minimize losses which may result from others' behaviors.

Olson (1968) applied these observations of human behavior to conclude that humans are rational, self-maximizing actors, and to describe scenarios in which people would (or would not) act collectively. Previously, social scientists assumed that if a group of people had a large enough grievance they would naturally self-organize, and inaction was viewed as unconventional behavior (Oliver, 1993). In *Logic,* Olson reframed collective action by suggesting that contributions were irrational unless the benefits outweighed the costs (Oliver, 1993). This framework changed the focus of collective action research toward exploring the motivations behind action, and reframed collection action from an exclusively moral endeavor, to a rational, calculated choice motivated by self-interest.

Olson's conclusions and thought experiments have since been deemed problematic, contradictory, and simply incorrect (Oliver, 1993; Ostrom, 1990). One of the main limitations of Olson's argument was that he assumed actors do not contribute without incentives. However, those incentives must themselves be provided by other actors in the system, which is an irrational contribution, thus undermining Olson's conclusion that all actors are self-maximizing (Oliver, 1993). However flawed, *Logic* launched a new mode of scholarship (Oliver, 1993; Sandler, 2015).

Garrett Hardin, in *Tragedy of the Commons* (1968), considered the prisoners' dilemma and self-maximizing actors to natural resource settings. Hardin presented another thought experiment, this time set in an open-access pasture where he assumed users (i.e., herdsmen) were rational, each maximizing their use of the resource (by adding additional cattle) until eventually the pasture would be depleted, undermining the ability of anyone to prosper (Hardin, 1968). Thus, Hardin concluded that individual rationality, where each user seeks to self-maximize, leads to collective irrationality, and depleted natural resources. He saw this tragedy of [open-access] commons as inescapable, especially with uncontrolled population growth (Hardin, 1968).

To avoid the "tragedy," Hardin (1968) recommended that resources be privatized, or regulations enforced by a central authority. This provocative and enduring essay suggested that natural resources would inevitably meet their demise if left to unchecked human behavior. *Tragedy of* *the Commons* also created an easy heuristic to explain overuse of natural resources, especially at a time when issues like global population and pollution were entering the public's consciousness. While simplistic, the *Tragedy of the Commons* is an almost universally assigned reading in conservation fields and is often a foundational text in the study of collective action as it pertains to natural resources. Its influence can be seen in natural resource policies which seek to solve similar issues by adopting Hardin's solutions of privatization or coercion by centralized authority (Ostrom, 1990).

The prisoner's dilemma, *Logic,* and the Tragedy of the Commons all stemmed from the same assumptions of the self-maximizing, rational actor whose behaviors lead to sub-optimal provisions of goods. All three works assume people will not restrain their behavior or contribute voluntarily to public goods, and therefore systems and governance structures must be established and enforced to promote optimal, or sustainable, outcomes. These high profile, easily comprehended heuristics, laid the groundwork for divergent collective action scholarship, with some researchers extending this line of thought, and others exploring exceptions and alternative explanations and solutions (Ostrom, 1990; Oliver, 1993).

One of the most prominent researchers to challenge Hardin's view was Elinor Ostrom who developed alternate theories of collective action. Her body of research complicated the *Tragedy of the Commons* by demonstrating that communities have long self-organized, through social and legal contracts, and created institutions to effectively manage common property (Ostrom, 1990). Through both economic games and empirical case studies, Ostrom found that communities, under the right circumstances, do in fact work collectively. Unlike Hardin, Ostrom demonstrated this could happen organically through social interaction, without the need for privatization or centralized authority. She argued that self-organized solutions were ignored by research and policy yet could lead to the same outcomes with no additional input or oversight from outside forces (Ostrom, 1990).

Ostrom's conclusion that communities could self-organize and do self-organize emerged from research focused on social benefits and dynamics not addressed by Hardin. She adjusted the assumptions of a rational actor by positing people had bounded rationality, where they could not possibly conceive of all relevant dimensions of natural resource problems (Ostrom, 1990). Further, actors likely considered the behavior of others when deciding their own behaviors, especially people they trusted. Ostrom also argued users were not simply short-term maximizers, but instead reflected on long-term strategies before committing to a course of action. These conclusions were summarized in *Governing the Commons*, where Ostrom (1990) laid out seven design principles for successful natural resource institutions which suggested both material and social conditions were necessary for institutional success. Her work, while still assuming people were rational actors, highlighted the importance of social dynamics, such as trust, when developing institutions to manage natural resources.

While Hardin and Ostrom took different positions on self-organization, their scholarship shared a common focus on actors in CPR regimes. Hardin theorized about collective action through a thought experiment of an open access common property, while Ostrom examined collective action in empirical case studies. These two perspectives initiated a field of natural resource collective action research, but their conclusions were limited to CPR systems. Different natural resources are governed by distinct social and ecological processes. While many natural resources do fit a CPR framework, others are better explained as public goods. CPRs and public goods have structural differences in their governance and the types of social interactions, each relevant for understanding collective action behavior.

Common Pool Resources

CPRs are resources large enough where it is costly, but not impossible, for people to exclude potential users, as well as rivalrous, meaning one actor's use of the resources detracts from another's potential use (Sandler, 2015). CPRs have defined boundaries, so use can be limited to a single person or group of individuals by restricting entry or the ability to take a unit of the resource (Ostrom, 1990). The defined boundary also allows actors to be divided into in-group and out-group members, where monitoring and sanctions can ensure that in-group members follow the rules, and out-group members are excluded (Ostrom, 1990). Natural resource CPRs are often thought of as stock resources, where there is some optimal flow of resource units that actors can consume sustainably (Ostrom, 1990). For example, classic examples of stock CPRs are fisheries or open grazing areas, where overuse can lead to depletion. The threat of overusing CPRs is often "solved" through rules limiting consumption, monitoring of those rules, and sanctions for violators (Ostrom, 1990). To implement these rules, a CPR needs a defined boundary that can be monitored and enforced (Ostrom, 1990).

Public Goods

While CPRs are stock resources that must be protected against unsustainable consumption, public goods must be produced by contributing actors. In most public good scenarios, no one person can single-handedly produce the public good for the benefit of a group, and no average contributor's action or inaction affects the likelihood a public good will be produced (Chong, 1991). For example, public radio needs a mass of donations to operate, but no one donation will affect the outcome of a donation drive. Public goods are in a sense boundless, because once the good is produced all contributors and non-contributors can equally enjoy its benefits (Chong, 1991). In large groups, some actors try to maximize their benefit by withholding contributions while still enjoying benefits of the public good. These actors are called "free-riders" (Chong, 1991). Problematically, free-riding is a rational decision which does maximize personal gain, but if too many people become free-riders, they will undermine the public good and everyone will be worse off than if they had all contributed a small amount (Chong, 1991). Small group dynamics are often different because the individual contributions required to provide the public good may be too costly for the good to be produced (Chong, 1991).

Collective Action in Weed Control

While there is a fundamental difference between the collective actions needed to sustain CPRs and produce public goods, weed control studies have not addressed this distinction. While many authors acknowledge weed control is a collective action problem, they are not clear as to what kind (Yung et al., 2015; Niemiec, 2016; Graham, 2013; Marshall et al., 2016). In the absence of a clear theoretical collective action framework, researchers and policy makers often assume a CPR framework, and adopt solutions such as Ostrom's design principles without critical examination. For example, some studies investigated sanctions and monitoring of landowners who do not control weeds (Graham, 2013; Hershdorfer et al., 2007;). A key component for land managers, such as extension agents, is enforcing weed control laws, and imposing fines on non-controlling landowners (Marshall, Coleman, Sindel, Reeve, & Berney, 2016; Klepeis et al., 2009). However, CPR solutions have limited success, often because of how difficult monitoring and sanctioning can be in rural systems where private ownership is common.

Rural properties are inherently difficult to monitor because many are remote, and in some cases, landowners take hasty control action right before an inspection to avoid sanctions instead of investing in long-term solutions (Feige, 2005; Klepeis et al., 2009). Many government officials who monitor properties for weeds are charged with overseeing several landowners over large areas (Epanchin-Niell et al., 2010), and access for monitoring may be optional for landowners. Landowners may be reluctant to allow land mangers on to their property both to avoid fines, and because landowners have a strong sense of private property rights and may see sanctions by a land manager as an infringement of those rights (Brunson, 1998; Yung & Belsky, 2007).

In the West, many landowners' sense of private property rights developed from early American philosophy, where, if a person "works the land," their betterment of the justifies their inherent right to the property (Brunson, 1998; Yung & Belsky, 2007). Suggestions about how to manage land by an outside entity may be seen as an intrusion on these property rights, and a may be viewed as a threat to landowners' "lifestyles as well as to their livelihoods" (Brunson, 1998, p. 77). Land managers are aware of this dynamic and are often unwilling to fine landowners because the fine may either damage the land manger's relationship with that landowner, or the land manger themselves does not want to infringe on an individual's rights (Fiege, 2005).

However, effective weed control requires landowners to continually, and voluntarily, engage in weed control for extended periods of time, and such commitments are facilitated through good relationships with extension agents and neighbors. Sanctioning landowners may lead them to become disillusioned with weed control and create social tensions with the land manager. They then may be less likely to engage in the costlier behavior of working with a land manager to establish long-term weed control plans, going to workshops or other types of voluntary engagement (Klepeis et al., 2009). In other situations, landowners may simply deny access for monitoring, or avoid related or unrelated voluntary programs which might enable monitoring by authorities. These monitoring limitations make weed control enforcement extremely challenging.

Studies have shown that responses from the CPR playbook are often ineffective at promoting weed control (Klepeis et al., 2009). Instead, research from political science may be of more utility for understanding how to motivate weed control behaviors (Chong, 1991). Motivations to contribute to public goods often center on moral and social benefits of contributions, rather than material benefits. For example, maintaining a good reputation is an important social incentive to participate in collective action.
(Milinski, Semmann, & Krambeck, 2002; Nowak and Sigmund, 2005; Chong, 1991). Individuals who value positive social relationships may make small contributions to a public good if others they care about are already contributing (Nowak and Sigmund, 2005; Chong, 1991). Once individuals make initial contributions they are more likely to make larger contributions in the future to maintain their reputation or because of feeling of moral responsibility. Examples from the Civil Rights movement reviewed by Chong (1991) found individuals who were willing to

engage in fairly costless activities, such as going to an activist meeting with a friend, were then more likely to take on costly activities, such as picketing.

Constraints on provision of public goods can stem from the group size of contributors (Chong, 1991). Group size dynamics produces an “assurance game” with two equilibria, one where all actors defect and one where all actors contribute (Chong, 1991). The defection equilibrium occurs if the group size is small, making contributions to produce the public good costly. In this scenario very few individuals will want to contribute, and the public good will not be produced. However, as group size grows additional individuals will share the cost of producing the public good, reducing individual contributions. Assurance games frequently devolve to the defection equilibrium because the first few contributors face the highest costs and may decide the cost is too high to initiate contributions (Chong, 1991). To avoid the defection equilibrium, it is critical to mobilize established groups rather than individuals (Chong, 1991). Mobilizing a group engages the social ties and reputations of members of that group. In these settings, while an individual may want to defect, it is harder to do so if those with whom they are close already participate. In addition, mobilizing a group lowers the cost of participation because initial costs are shared.

It can also be difficult to maintain contributions in assurance games. High participation rates incentivize free-riding behavior. However, when free riders become too numerous, costs for contributors become too high and defections mount (Schelling, 1978). Charismatic leaders who maintain others’ participation, and a few irrational actors who maintain contributions regardless of cost can both help prevent defection by maintaining the moral core of participation (Chong, 1991). An assurance game resembles a prisoner's dilemma in that as some actors defect, others are left with the options of (a) continuing to contribute or (b) also defect (Chong 1991). Most individuals do not want to be left paying high costs for others' gain, so they will choose to defect, creating suboptimal results for everyone (Chong, 1991). The constraints to producing the public good shift with group size and are both important to consider when attempting to maintain sustained contributions.

The collective nature of weed control problems resemble some attributes of assurance games, yet diverge in important ways, primarily because weed control is an imperfect public good where individuals do gain some private benefits from controlling for weeds on their land. A landowner cannot totally rely on the group to produce a weed free environment, because they too have to engage in some control. However, if a landowner is satisfied with weed control in their area they may be less likely to act. Other landowners may tolerate some weeds on their property, if, in general, they live in a weed-free environment. While imperfect, these landowners may operate as free-riders in a weed control problem, creating defection patterns similar to those observed in other collective action problems.

Even through weed control is not a perfect public good, findings from the political science may still be relevant and prescient for understanding and promoting landowner weed control behaviors. For example, peer-to-peer interactions may catalyze normative pressures among landowners, where active landowners encourage others to participate in weed control events, such as skills workshops, or make additional investments in weed control efforts. When weed control is associated with landowners' reputations and identity, weed control efforts may increase. This could be achieved by using the local newspaper to publicly congratulate landowners who control for weeds. In other settings, these methods of encouraging behavior have been shown to sustain collective action (Panchanathan & Boyd, 2004).

Correctly identifying natural resource problems as public goods is important not only in weed control practice, but also for future weed control research. Bryce et al. (2014) increased the control of invasive mink by working across an entire watershed, rather than intercepting mink at an established perimeter, thus addressing the boundless nature of the public good (i.e., mink control). They also mobilized a large and active volunteer force, by giving participants ownership over certain capture sites, thus mobilizing norms of responsibility (Bryce et al., 2011). This example demonstrates how management policies guided by the public good framework can enhance outcomes.

Correct theoretical framing of collective action problems reveals subtle, but important, social dynamics that influence whether a community will effectively control. Minato et al. (2010) found that a small community in Victoria, Australia was able to eliminate blackberry from the valley through social sanctions and no additional government intervention. This community saw weed control as something that "ought" to be done, and the community instilled this norm through formal and informal means (Minato, Curtis, & Allan, 2010). They developed a program that paired new landowners with older residents to help both pass along weed control knowledge and community expectations (Minato et al., 2010). Also, if a landowner did not control for weeds there was both indirect "gossip" about their inaction, or sometimes direct confrontation by other landowners (Minato et al., 2010). By recognizing moral and social components to weed control

Minato et al. (2010) were able to draw out key social dynamics that contributed to successful control.

Monitoring and sanctioning are often incompatible with encouraging voluntary behavior, however they do play a specific role in stopping the spread of invasive species onto islands. Australia and New Zealand have implemented strict biosecurity regulations, including intercepting ships before they dock and plant quantities, to insure no one entering the country could bring any invasive species in (Simberloff et al., 2013). This scenario resembles a CPR problem where close to perfect monitoring can occur because there are defined boundaries and limited entry into the country. There are also definite in-group and out-group members rules can be developed and clearly enforced. The defined boundaries of islands provide an unusual situation where monitoring and enforcement can be close to perfect, and successful in reducing the spread of IS.

Limitations

The results and discussion presented here are based my review of the weed control literature and deductions from examples in the political science literature. Further research, especially empirically based, is needed to test my ideas. One possible limitation to my analysis is that weed control is a complex and enduring problem, with some studies showing that landowners see it as a "losing battle" (Yung et al., 2015). The harsh reality of weed control is that control efforts may ultimately be futile, and heavy monitoring and fines may be the most efficient way to address the problem. Hershdorfer et al. (2007) found that the presence of sanctions was more important than enforcing them. Defeated landowners may need a high level of external motivation to inspire control behaviors. Minato et al. (2010) found that even through residents had set up an effective culture of weed control, they still wished the government would fine non-cooperating landowners. This indicates there may be a place for monitoring and sanctioning to encourage weed control, but the tensions and complexities between CPR and public good approaches must be acknowledged and understood in more detail.

Conclusion

While there are limits to my analysis and more research is needed, I believe it is clear that weed control a collective action problem and within that framework, should be categorized as a public good problem, not a CPR problem. In the absence of perfect monitoring, effective weed control requires voluntary and sustained efforts by landowners, rather than limits on consumption. Restraining behavior is often needed to maintain a stock resource, while public goods need to be generated by action. In the case of weed control, the public good of a weed-free environment needs to be produced by a coordinated effort among landowners. However, the utility of reframing weeds as a public good needs to be quantified by future research. What empirical evidence definitively classifies weeds as either a public good or a CPR? Are intervention programs designed on public good theory more effective than those informed by CPR theory? Does engaging deeply with either (or both, and in what ways?) literature provide unique insights for inspiring behavioral changes among landowners? Other important questions also remain. For example, how important are social dynamics in determining weed control behavior, and what actions can land managers take to inspire novel solutions to weed control? Based on my analysis, however, I think it is clear there is a tension between monitoring and sanction enforcement, key tenants of CPR problems, and efforts to inspire voluntary control efforts which public goods require. Land managers, instead of focusing on sanctions, could benefit from increased attention to weed control norms and social support systems for participating landowners.

The theoretical distinction between CPRs and public goods has implications beyond weed control for many other resource conservation efforts. Encouraging people to take any conservation action with collective action elements, whether it be stream restoration or securing wildlife attractants, will require researchers and practitioners to understand and actively engage with social norms and dynamics. Still, in many conservation contexts, constraining behavior is necessary, which still sometimes require monitoring and the threat of sanctions for non-compliance. In these settings, building relationships and promoting social norms is an entirely different and likely contradictory approach to conducting sanctioning and enforcement actions. Adopting a public good framework changes the role of land manager from enforcer to facilitator (Costello et al., 2017; Ostrom, 2000). These roles may be confused when an official who is generally facilitating voluntary contributions must enforce sanctions, even if the enforcement is on an unrelated violation. In these instances, landowners may be wary of all government employees because some implement sanctions. For example, a landowner who has noxious weeds on their property maybe unwilling to have an extension agent on their property to develop a weed control plan because they want to avoid the possible fine for noxious weeds. When developing a natural resource programs, managers must not only correctly diagnose the collective action nature of the problem, they must also recognize the structures of other programs that might interfere with their efforts.

At a minimum, critical application of CPR, public good, and other collective action theories is needed in the weed control literature. Different frames beg different questions and opportunities; testing and theoretical development are needed to find those approaches most effective at achieving weed control objectives. More detailed consideration of collective action theory is likely to help researchers more clearly understand the social dynamics driving landowner weed control behaviors, and practitioners design more effective weed control programs. It is my hope that more rigorous engagement with collective action theory will catalyze novel, effective, and long-lasting solutions to weed control problems.

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