Research

Collective factors drive individual invasive species control behaviors: evidence from private lands in Montana, USA

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ABSTRACT. Invasive terrestrial plants globally threaten agricultural and natural systems. Prolific dispersal mechanisms enable "weeds" to colonize across ownership boundaries, constituting a collective action problem where effective control requires contributions from multiple actors. Researchers have long recognized the cross-boundary nature of weed control, yet most studies have focused on whether actor-specific characteristics, such as sociodemographics and cognition, influenced individual weed control behaviors. More recent work has begun to explore the drivers of communal control efforts, i.e., cooperatives, group actions. Few studies have empirically investigated how the collective aspects of weed invasions influence individual control behaviors. Here we provide quantitative evidence of a relationship between collective aspects of the weed control problem and landowners' willingness to engage in individual weed control efforts. In a mail-back survey of Montana landowners (n = 1327) we found collective factors, such as injunctive norms and the belief that weeds are a cross-boundary problem, were significantly correlated with willingness to engage in three different weed control behaviors. Each behavior was correlated with a unique suite of collective factors suggesting that successful interventions must be behavior-specific. These results add to a growing body of evidence that the collective nature of invasive species control is critical for understanding human behavioral responses.

Key Words: *collective action; conservation; Montana; private lands; weed control*

INTRODUCTION

The spread of invasive species is one of the leading drivers of global environmental change (Simberloff et al. 2013). In terrestrial systems, invasive plants (hereafter, "weeds"), whether native or exotic, outcompete endemic plants and alter ecosystems through adaptive strategies that allow rapid spread, challenging human efforts to control them (Baker 1974, Nackley et al. 2017, Zimdahl 2018). Weeds threaten global biodiversity (Parker et al. 1999) and have significant economic impact, especially in agricultural systems where their presence reduces quality, efficacy, and functionality in production (Sheley and Smith 2012). 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, in most systems, particularly those with complex ownership mosaics, effective weed control requires contributions from many actors. In landscapes where the individual decisions of private landowners aggregate to influence ecological outcomes over broad scales (Odum 1982), weed control becomes a collective action problem. In these social dilemmas, the behaviors of one actor affects others, creating negative externalities regardless of consent (Kollock 1998). To date, most research on weed control efforts has explored how actor-specific characteristics, such as sociodemographics and cognitions, influence individual weed control behaviors on private land (Sheley et al. 1996, Steele et al. 2006, Marshall et al. 2011, Fischer and Charnley 2012). More recent work has begun to explore the drivers of communal control efforts, i.e., cooperatives, group actions (Hershdorfer et al. 2007, Aslan et al. 2009, Reid et al. 2009, Marshall et al. 2016, Graham and Rogers 2017, McKieran 2017). Few studies have empirically investigated how the collective aspects of the problem influence individual weed control behaviors (Epanchin-Niell et al. 2010,

Minato et al. 2010). To mitigate the threat weeds pose to important social and ecological systems around the world, it is critical to understand how landowners' individual behaviors are affected by the collective nature of the problem.

In collective action problems, human behaviors are driven by both individual and collective factors (Ostrom 1990, Chong 1991). Individual factors are characteristic specific to each actor, such as age, gender, financial resources, knowledge, physical ability, attitudes, and beliefs. In contrast, collective factors are those that derive from the collective nature of the problem, such as awareness of cross-boundary interrelationships, beliefs about normative behaviors or expectations, or confidence that collective efforts can achieve desired outcomes. Collective factors can be externally imposed on actors, such as social sanctions, or internally motivated, such as the desire to be a good neighbor. In many different contexts, research has demonstrated that human behaviors are often heavily influenced by collective factors (Ostrom 1990, Chong 1991, Finkel and Muller 1998). For example, game theory research has demonstrated that individuals alter behavior to maintain reputation and social standing (Chong 1991, Milinski et al. 2002, Nowak and Sigmund 2005), based on normative beliefs (Finkel and Muller 1998), or in response to face-to-face interactions with others (Ostrom 1990).

Despite the collective nature of weed control, most human dimensions research has focused on the individual factors that drive weed control behaviors (García-Llorente et al. 2008, Sheley et al. 2010, Selge et al. 2011). For example, researchers have found that attitudes toward specific species affect evaluations of acceptable management responses, and those unconcerned about weeds are less likely to control than others whose livelihoods are impacted by weeds or for whom biodiversity is a management

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goal (Marshall et al. 2011, Fischer and Charnley 2012). Frequent constraints to weed control behaviors include lack of time, money, and knowledge (Sheley et al. 2010, Yung et al. 2015). Many landowners do not know how weeds spread and are unable to correctly identify weed species (Aslan et al. 2009, Sheley et al. 2010, Fischer and Charnley 2012). However, across studies, many authors acknowledge the importance of cross-boundary or collective factors, even if they do not specifically incorporate these dimensions into models of individual behavior (Reid et al. 2009, Epanchin-Niell et al. 2010, Yung et al. 2015, Marshall et al. 2016, Niemiec et al. 2016). For instance, Yung et al. (2015) found that many landowners believed their weed control efforts were undermined by weed seeds dispersed from neighboring properties, and Niemiec et al. (2016) observed people who felt discouraged from controlling an invasive tree in Hawai'i because they perceived a lack of participation or coordination among neighboring landowners. In other contexts, landowners did not trust that newer, amenity owners, i.e., those who move to rural areas for the lifestyle rather than to work the land, would implement effective control, thus undermining the efforts of more long-term landowners to control weeds (Yung and Belsky 2007, Klepeis et al. 2009, Graham 2013, Epanchin-Niell and Wilen 2015).

There is growing recognition that more work is needed to understand the collective aspects of weed control (Bagavathiannan et al. 2019, Graham et al. 2019), yet the developing literature is mostly qualitative, or focused on collective actions, such as those organized by collaborative weed groups, rather than on individual actions (Hershdorfer et al. 2007, Graham 2013, Marshall et al. 2016, Graham and Rogers 2017). Qualitative accounts of efforts to control weeds are useful for understanding unique contexts or developing broader hypotheses, yet do not allow for generalization on their own. So, although there is evidence suggesting some landowner control efforts are driven by a motivation to be good neighbors and the expectation that others will reciprocate (Yung and Belsky 2007, Klepeis et al. 2009, Yung et al. 2015, Niemiec et al. 2016, Marshall et al. 2016), or that some communities enforce weed control norms through social control mechanisms such as gossiping (Merry 1984, Minato et al. 2010), the degree to which these collective factors broadly influence weed control behaviors is unknown, especially after controlling for important individual factors. Similarly, although collective actions for weed control may be particularly effective, many control decisions are made by individual landowners in an individual context, i.e., treating their own land, not part of a cooperative effort. Collective responses to weed control have received increased attention in recent years, leaving understudied the role of collective factors in driving individual behaviors (Graham et al. 2019).

Research purpose and questions
With this study we sought to quantify the role of collective factors in determining landowners' individual weed control behaviors. We hypothesized that individual weed control on private lands is a collective action problem because, holding individual factors constant, collective factors would explain significant variation in individual landowner weed control behaviors. More specifically, for our application of the collective interest model (CIM) we drew independent variables from the extant qualitative weed control research and broader collective action literature, including the following: injunctive and descriptive normative beliefs (Nowak

and Sigmund 2005, Yung and Belsky 2007, Marshall et al. 2016, McKiernan 2017), the recognition that weed control is a cross-boundary problem (Fiege 2005, Marshall 2009, Yung et al. 2015), reciprocity (Kollock 1998, Ostrom 2000, Panchanathan and Boyd 2004, Marshall et al. 2016), area-wide satisfaction with weed management (Finkel and Muller 1998, Reid et al. 2009, Graham and Rogers 2017), sense of community (Graham and Rogers 2017), and group efficacy (Chong 1991, Finkel and Muller 1998, Epanchin-Niell et al. 2010). Previous literature has established the relationship between individual factors and individual weed control behaviors. Here, we extend this line of research by quantifying the additional variance in weed control behavior explained by collective factors. With this approach we provide a more complete understanding of individual landowners' utility calculus when choosing to control for weeds and offer insights for improving future research and outreach efforts seeking to explain or promote weed control on private lands.

METHODS

Collective interest model
To accomplish these research goals, we employed the collective interest model (CIM, Eqn. 1) to analyze landowner responses to a mail-back questionnaire. The CIM was first developed to explain political protest behavior and has since been used to investigate behaviors in a variety of collective action situations including environmental activism and collective housing behaviors (Finkel and Muller 1998, Lubell 2002, Yau 2011). The CIM allows associations between behaviors of interest and individual as well as collective factors, including (i) an individual's value of the public goods provided by the action, (ii) the extent to which an individual thinks their personal actions can affect the provisioning of the public good, i.e., individual efficacy, (iii) the extent to which an individual believes the group can successfully achieve their aim, i.e., group efficacy, and (iv) the costs and benefits of engaging in behavior, including financial, emotional, and cognitive costs, such as attitudes, norms, knowledge, values. Employing the CIM allowed us to combine individual factors that have been established in the weed control literature with collective factors to compare their relative importance to individual weed control behaviors (Finkel and Muller 1998). The CIM is conceptualized as.

$$EV = [(p_i + p_g) * V] + B - C \tag{1}$$

where EV is the expected value of behavior, p_i is individual efficacy, p_g is group efficacy, V is the value of the outcome of the collective behavior, B is the benefits of engaging in the behavior, and C is the costs of engaging in the behavior (Finkel et al. 1989).

The CIM was applied once before to investigate weed control, but with respect to collective rather than individual behaviors. Niemiec et al. (2016) used the CIM in a study from the Puna district of Hawai'i, where non-native albizia trees, *Falcataria moluccana,* were dropping branches after a hurricane, causing dramatic and costly damage to cars and homes. The CIM proved useful for explaining substantial variance in "activism" behaviors such as teaching a neighbor how to remove albizia or removing albizia from a public space (Niemiec et al. 2016). It remains unclear, however, if collective factors operationalized by these authors also explain variation in individual weed control

behaviors, or if their effects are limited to collective behaviors related to this invasive tree.

Study site

The state of Montana, USA provided an ideal context to study landowners' weed control because weeds have long been a problem there and 60% of land is privately owned. 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 prevalent in many counties, and 20 other, less abundant noxious weed species (Montana Department of Agriculture 2017). Montana invests in extensive outreach efforts to encourage landowners to control for weeds, including enforcement, landowner workshops, newsletters, billboards, and other marketing materials. A recent assessment estimated that invasive weeds cost the state of Montana well over $100 million annually, with an additional $25 to $50 million invested in research, outreach, education, monitoring, and control (Creative Resource Strategies LLC 2016), significant investments for a state with only just over 1 million residents.

Data collection

We collected data for this study using a mail-back questionnaire sent to Montana private landowners (Appendix 1). Our sampling frame included nonpublic landowners owning between 0.2 and 2500 hectares of land outside of incorporated city limits. We focused on mid- and smaller sized parcels in these areas because our extension agent study partners, i.e., university staff/faculty who offer natural resource training programs, saw them as a particularly challenging group to motivate into weed control action. We regionally stratified the sample, i.e., western, central, and eastern regions (Fig. 1), to ensure adequate representation of landowners from across the state because population density in Montana is higher in the west and lower in the east. To address this sampling concern we established regions based on administrative boundaries used by state agencies that were familiar and meaningful to our practitioner study partners. We drew an initial sample of 4500 landowners (1500 per region) using the Montana cadastral data (Base Map Service Center Montana State Library, http://svc.mt.gov/msl/mtcadastral). We pretested the questionnaire with four university graduate students and faculty, four employees from a state natural resource agency, and three 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 nonrespondents, with each mailing spaced approximately two weeks apart. All research methods were approved by our university's Institutional Review Board prior to administration.

Adapted collective interest model

In our adaption of the CIM we predicted that individuals would be more willing to engage in weed control if, (i) they believed their weed control actions would be successful, (ii) they believed those around them were also controlling, (iii) they believed control efforts by themselves and other landowners could provide benefits, (iv) they valued a weed free environment, and (v) if actions were not too costly, defined broadly to include financial, informational, and social costs and benefits. Below we describe how we operationalized each of these factors, including

adaptation of extant measures from previous research on collective action problems (Finkel and Muller 1998, Lubell et al. 2007, Niemiec et al. 2016), and novel metrics.

Fig. 1. Map of Montana with the three regions, Western, Central and Eastern, used in survey implementation. Areas shown in green are public lands.
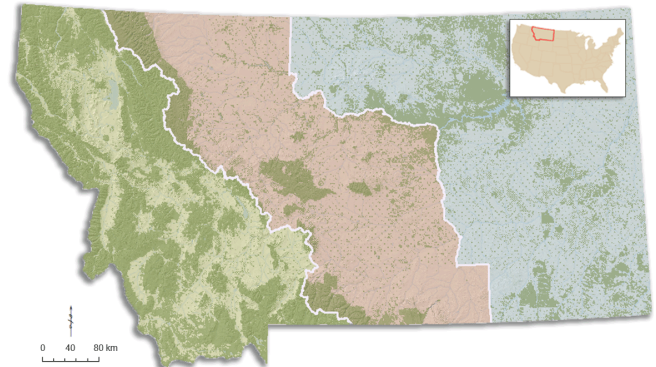
Dependent variables

We tested the model using four dependent variables: willingness to (i) work with an extension professional to develop a weed control plan, (ii) use herbicides to control weeds, (iii) release biocontrol, i.e., insects, to control weeds, and (iv) spend time pulling weeds on your property (Table 1). We conceptualized willingness as a behavioral intention, a precursor to behavior (Ajzen and Fishbein 2005). We chose these behavioral intentions as dependent variables because we were unable to independently observe actual behaviors, and self-reported weed control behaviors may be particularly problematic in Montana because landowners in the state are legally responsible for controlling noxious weeds (MCA Section 7-22-2116) which might lead to overstatements. Each dependent variable was measured on a five-point Likert scale from "very unwilling" to "very willing" (Table 1).

Independent variables

We drew independent variables from literature pertaining to invasive species control on private land, and other collective action research. Each independent variable was classified as an "individual" or "collective" factor, and measured on a five-point Likert-scale with unique anchors, with the exception of the descriptive norm, the injunctive norm, and network centrality variables, which were measured on dichotomous "yes/no" scales (Table 1).

Individual factors

We included several individual factors as covariates in the model that past research has found related to landowners' decisions to control weeds. Personal efficacy (p_i), measured whether an individual believed their actions would contribute to the collective outcome. To measure p_i, we asked landowners if they felt their personal actions could help control for weeds on their property (Table 1, adapted from Niemiec et al. 2016). We measured individuals' valuation of the individual benefit, a weed-free environment (V), by asking landowners to rate their level of concern about weeds affecting various aspects of their property (Table 1).

Table 1. Constructs and descriptive statistics for the survey organized using the collective interest model.

	CIM designation	Scale	Mean	Standard Deviation	Cronbach's Alpha
Dependent[†]					
Work with an extension professional to develop a weed control plan for your property	EV	5-point Very unwilling–Very willing	3.72	0.926	
Use herbicides to control weeds	EV	5-point Very unwilling–Very willing	3.95	0.991	
Release biocontrol (insects) to control weeds	EV	5-point Very unwilling–Very willing	3.73	1.01	
Spend time pulling weeds from your property	EV	5-point Very unwilling–Very willing	3.83	0.992	
Independent: Collective					
Cross-boundary belief	P_g	5-point Strongly disagree–Strongly agree	4.12	0.781	
Reciprocity-notice or hear	P_g	5-point Strongly disagree–Strongly agree	3.36	0.968	
Reciprocity-motivate to act	P_g	5-point Strongly disagree–Strongly agree	3.03	0.99	
Generalized group efficacy	P_g	5-point Strongly disagree–Strongly agree	3.85	0.884	
Area wide satisfaction	P_g	5-point Very unsatisfied–Very satisfied	2.98	0.983	
Network centrality-ask opinion	C/B	Dichotomous Y/N	1.28	0.449	
Network centrality-influence opinion	C/B	Dichotomous Y/N	1.27	0.445	
Descriptive norm	C/B	Dichotomous Y/N	1.44	0.497	
Injunctive norm	C/B	Dichotomous Y/N	1.54	0.499	
Sense of Community	C/B		3.93	0.830	
Sense of Community 1-"Strong sense of community"	C/B	5-point Strongly disagree–Strongly agree	3.52	0.932	.843
Sense of Community 2-"People can solve area problems"	C/B	5-point Strongly disagree–Strongly agree	3.47	0.913	
Sense of Community 3-"I have influence over the community"	C/B	5-point Strongly disagree–Strongly agree	3.16	0.953	
Sense of Community 4-"I take an active role in solving area problems"	C/B	5-point Strongly disagree–Strongly agree	3.20	0.926	
Independent: Individual					
Personal efficacy	P_i	5-point Strongly disagree–Strongly agree	4.11	0.773	
Concern about private property	V		3.93	0.83	
Concern 1-"Enjoyment"	V	5-point Strongly disagree–Strongly agree	4.09	0.903	.907
Concern 2-"Economic Value"	V	5-point Strongly disagree–Strongly agree	4.03	0.909	
Concern 3-"Productivity"	V	5-point Strongly disagree–Strongly agree	3.91	0.994	
Concern 4-"Aesthesis"	V	5-point Strongly disagree–Strongly agree	3.46	0.896	
Concern 5-"Ability to Use"	V	5-point Strongly disagree–Strongly agree	3.46	1.11	
Money	C/B	5-point Strongly disagree–Strongly agree	3.28	1.12	
Time	C/B	5-point Strongly disagree–Strongly agree	3.18	1.12	
Confidence in ability to identity weeds	C/B	5-point Strongly disagree–Strongly agree	3.48	1.09	
Confidence in ability to control	C/B	5-point Strongly disagree–Strongly agree	3.43	1.08	
Trust the government to control for weeds	C/B	5-point Strongly disagree–Strongly agree	2.17	0.958	

Age	C/B	Open response	64.32	12.88
Biocentric environmental belief	C/B	5-point Strongly disagree–Strongly agree	3.77	1.02
Anthropocentric environmental belief	C/B	5-point Strongly disagree–Strongly agree	2.25	1.05
Education	C/B	5 Categories: Grade school, High school/GED, Some college, College graduate, Post graduate	Mode = Some College	
Income	C/B	9 Categories: >$9999, $10,000–$19,999, $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	Mode = $60,000–$79,000	
Acreage	C/B	Open response	Median = 20	
Gender	C/B	Male/ Female	Male 63.5% Female 28.8%	

[†] Exact wording included in supplemental material.

Engaging in weed control may require material resources (C) and/ or provide social and psychological benefits (B; Yung et al. 2015). We used sociodemographic information provided by respondents to determine how easily they could afford the costs (C) of completing control behavior. These included age, income, education level, acreage, and gender (adapted from Lubell et al. 2007 and Niemiec et al. 2016). To measure the psychological benefits of engaging in weed control we measured biocentric and anthropocentric environmental beliefs using scales from the new environmental paradigm (Dunlap and Van Liere 1978).

Collective factors
We included in the model several collective factors predicted to explain variance in weed control behavior (Table 1). We conceptualized group efficacy (p_g) as a combination of whether an individual believed that weed control was a collective problem, that landowners in their area could be successful controlling for weeds, that those around them were controlling for weeds or could be inspired to control, and that current weed control efforts in their area were satisfactory (adapted from Niemiec et al. 2016). To measure if a landowner believed that others around them were contributing, we asked landowners if they felt most people in their area were controlling for weeds. To measure if a landowner believed that others could be inspired to control for weeds, we asked landowners if other landowners would notice their weed control efforts, and if their weed control efforts would inspire others to reciprocate. To evaluate a landowner's perception of weed control on lands near their property, we asked if they were satisfied with weed control in their general area.

To measure the costs and benefits (C/B) that landowners might incur from weed control, monetary and otherwise, we included several additional questions (Table 1). To start, we asked respondents if they believed they had enough (i) time, (ii) money, and (iii) knowhow (including identifying weeds and knowing how to control them). We also included a measure of (iv) injunctive and (v) descriptive norms regarding weed control to measure the potential social benefits or sanctions of engaging in weed control (Klepeis et al. 2009, Niemiec et al. 2016). Additionally, we measured (vi) network centrality for each landowner (adapted

from Lubell et al. 2007), assuming the more people landowners communicated with about weeds, the lower their costs of acquiring information necessary for control. Communication about a collective problem has been shown to encourage collaborative behaviors by those involved in the collective problem (Janssen 2013). We included a (vii) "sense of community" scale, which used four items to measure if a landowner felt supported by their community, and whether or not they were an effective agent in their community (adapted from Absher et al. 2013). Like network centrality, we posited that if an individual was generally an active member of the community they would have a lower cost of obtaining help or receiving information about weed control (Graham and Rogers 2017).

Prior to analysis, we created two composite variables from these independent variable items: (i) "concern" was calculated as the mean response across five items measuring different ways weeds might negatively affect landowners' properties, and (ii) "sense of community" was calculated as the mean response across 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's alpha test with a 0.65 cut-off (Vaske 2008; Table 1).

Analysis
To test our hypotheses we conducted an ordinary least squares (OLS) regression for each of our dependent variables, a common approach to CIM analyses (Lubell et al. 2007, Yau 2011, Niemiec et al. 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,

$$EV\,(weed\,control\,behaviors) = p_i + p_g + V + B - C \qquad (2)$$

which allows for the simplest interpretation of significant variables (Lubell et al. 2007). In some cases this adaption of the CIM may increase the relative importance of benefits and costs because there is no amplifying effect between personal and group efficacy and the value of the outcome. To test OLS assumptions

we reviewed descriptive statistics of each variable to confirm normality, linear relationships with dependent variables, and homoscedasticity. We used variance of inflation factor (VIF) procedures to determine there was no multicollinearity, and P-P plots to determine if residuals were normally distributed (Vaske 2008). To account for sampling design, we weighted responses by region (Vaske 2008). We performed all analyses using IBM SPSS Statistics 24.

As a nonresponse check, we conducted independent t-tests comparing respondents to nonrespondents across several variables available in the Montana cadastral dataset, including land value, total value, building value, total property size, and hectares of land in farm, grazing, forest, fallow, irrigated, wild hay, and nonquality, i.e., unsuitable for farming. We used a *p*-value of 0.05 to detect significant differences between respondents and nonrespondents.

RESULTS
The initial sample size was reduced to 4424 after we removed duplicate and incorrect addresses. Respondents totaled 1327 for a response rate of 30%. Respondents were generally well educated with 51% of landowners having a college degree or higher, older with an average age of 64 years, 69% male, and of higher incomes with 34% earning over $100,000 of annual household income. This sociodemographic profile is generally consistent with landowner populations across the U.S. Although we included region as a covariate in our analyses, it was never significant and thus excluded from presentation here. Descriptive statistics for all variables are shown in Table 1, with values weighted to represent statewide inference to our sampling frame.

Residual plots indicated normal distributions for three of the 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 thus excluded this measure from further analysis. We determined there was no multicollinearity using VIF procedures. We found no differences between respondents and nonrespondents in our sample with two minor exceptions: respondents had slightly more hectares of wild hay ($p = 0.004$) and nonquality land ($p = 0.019$). Respondents owned an average of 0.99 ha of wild hay and 1.15 ha of nonquality land, while nonrespondents had an average of 0.68 ha of wild hay and 1.36 ha nonquality land. Across all other variables, respondents were not significantly different from nonrespondents. Given these small differences, we proceeded with the assumption our respondents were representative of the broader population defined by our sampling frame.

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.

Weed control behaviors
We found collective factors were significant for each behavior, although each dependent variable generated unique results (Table 2). Three collective measures were significant and positively correlated with "willingness to work with an extension professional": the belief that weed control was a collective problem, group efficacy, and sense of community. Three individual beliefs were also significant and negatively correlated with this dependent variable: having enough money, confidence in weed control ability, and the anthropocentric environmental belief. Income was the only individual variable positively correlated with this dependent variable, and it was the strongest predictor (Table 2). Two collective measures were significant and positively correlated with "willingness to use herbicides": the belief that weed control was a collective problem, and the injunctive social norm. Two individual factors were significant and negatively correlated with this dependent variable: concern about weeds, and the biocentric environmental belief. Income was once again positively correlated and also the strongest predictor of this behavioral intention (Table 2). Network centrality was the sole collective factor that was significantly and positively correlated with "willingness to release biocontrol." Two individual factors were significantly positively correlated with this dependent variable: concern about weeds, and education. Two individual factors were significant yet negatively correlated: having enough money, and the anthropocentric environmental belief (Table 2).

DISCUSSION
Here we employed a quantitative model to investigate the relationship between collective factors and independent weed control behaviors on private lands. Our results indicated that collective factors were significantly related to individuals' willingness to take individual action to control for weeds on their properties. Collective factors were correlated with each weed control behavior, suggesting their importance across a variety of weed control interventions. The significance of collective factors, even across our large study site and broad context of weed control, e.g., species and situationally generic, and with a broad array of individual factors accounted for, show they are essential for understanding landowner weed control decisions and may provide useful insight for those attempting to encourage more robust control measures on private lands.

Our results corroborate what has been established in political science and game theory research, but has been previously overlooked in the weed control literature: individuals making seemingly autonomous decisions are influenced by the collective nature of the problems they encounter (Schelling 1971, Chong 1991, Kollock 1998, Ostrom 2000, Milinski et al. 2002). In Montana at least, the factors motivating landowners to control for weeds mirror the motivations for others to engage in a variety of collective action problems. Specifically, landowners' behaviors were correlated with injunctive normative beliefs, important motivators for political activism participation (Chong 1991), reciprocity, an important factor leading to cooperation in economic games (Milinski et al. 2002), as well as environmental activism (Lubell et al. 2006), and network centrality, which has enabled residents in other settings to engage in recycling programs (Everett and Peirce 1991). This adds an important dimension to the growing body of literature recognizing the collective dynamics relevant to invasive species management, but which has focused more on coordinated responses rather than individual behaviors (Graham et al. 2019). Natural resource research and practice would benefit by more deliberately engaging with collective action research from across disciplines to understand how collective

Table 2. Selected independent variable from the collective interest model predicting willingness to engage in invasive species control behaviors, based on ordinary least squares (OLS) regression models.

		Dependent Variables								
		Work with an Extension Professional to make a plan $R^2 = 0.201$			Use Herbicides $R^2 = 0.248$			Use Biocontrol $R^2 = 0.197$		
Independent Variables										
Type	Name	$\beta^\dagger$	S.E.	p	β	S.E.	p	β	S.E.	p
	Constant	2.463	0.513	0.000	0.747	0.502	0.138	1.36	0.532	0.011
Collective	Cross-boundary belief	0.277	0.081	0.001	0.281	0.08	0.00	0.077	0.084	0.365
	Generalized Group efficacy	0.116	0.067	0.083	0.046	0.065	0.479	0.036	0.069	0.604
	Sense of Community	0.118	0.068	0.086	0.176	0.067	0.009	0.100	0.071	0.157
	Reciprocity- motivate to act	0.04	0.116	0.523	-0.001	0.061	0.985	0.111	0.065	0.089
	Network centrality-ask your opinion	-0.012	0.118	0.919	0.077	0.112	0.494	0.276	0.118	0.02
	Injunctive norm	0.17	0.104	0.100	0.178	0.062	0.08	0.044	0.107	0.678
Individual	Anthropocentric environmental belief	-0.086	0.049	0.084	0.069	0.157	0.157	-0.108	0.051	0.034
	Biocentric environmental belief	0.007	0.892	0.892	-0.103	0.05	0.038	0.04	0.052	0.441
	Concern	0.029	0.052	0.639	0.169	0.061	0.006	0.233	0.065	0.00
	Education	0.048	0.045	0.282	-0.018	0.044	0.689	0.117	0.046	0.012
	Money	-0.111	0.054	0.041	0.006	0.053	0.917	-0.129	0.056	0.021
	Confidence in ability to control	-0.163	0.063	0.011	0.017	0.062	0.787	-0.052	0.066	0.426
	Income	0.326	0.171	0.056	0.369	0.167	.023	-0.055	0.176	0.755

[†] Coefficients are unstandardized.

factors influence individual's land management decisions, and how to better design interventions to motivate contributions to the public good of weed control.

Although collective factors were significantly correlated to each weed control behavior, relevant factors varied among behaviors, suggesting a need for outreach to be behaviorally specific. Take for example, "willingness to work with an extension agent," which was positively correlated with group efficacy, sense of community, and reciprocity. This finding suggests that landowners who saw themselves in a community that takes action to control weeds, and solve other problems, were more willing to seek professional assistance toward weed control. In contrast, the significance of injunctive normative beliefs to landowner "willingness to use herbicides" suggests this particular behavior could be promoted by elevating the belief that neighbors expected each other to control for weeds. Clearly, weed control behaviors are viewed distinctly by Montana landowners because each behavior was correlated with different factors. This has important implications for outreach and intervention programs, because those seeking to inspire increased control must understand that each behavior may require unique intervention strategies.

Individual factors were also correlated with unique behaviors, further emphasizing the need to tailor messaging to each behavior. For example, education was only significantly related to "willingness to release biocontrol," possibly reflecting that unique knowledge was needed to understand, implement, or accept biocontrol. Individuals' values were also correlated with unique behaviors, for instance, those with higher anthropocentric environmental beliefs were less "willing to work with an extension professional" and "release biocontrol." These results are consistent with others' findings, such as Selinske et al. (2016) who found that environmental beliefs influenced private landowners' decisions to engage in conservation initiatives. Taken together, these results underscore the conclusion that the most impactful outreach is oriented toward specific behaviors of interest and tailors messaging to induce such change (McKenzie-Mohr 2011, Amel et al. 2017). Importantly, however, messages promoting certain collective factors, such as emphasizing social normative beliefs, may motivate some, but not all, landowners to control weeds. Multiple pathways toward behavior change are needed as landowners and other audiences hold diverse motivations and constraints.

Concern about weeds was high across our sample suggesting weed campaigns that seek to increase concern may affect little behavior change (Amel et al. 2017). Rather than adding to the tens of millions spent toward raising awareness, a more effective approach might be to emphasize collective aspects of this issue, even using the same communication modes (McKenzie-Mohr et al. 2012). Billboards that celebrate control efforts by local landowners could serve to elevate both injunctive and descriptive norms around weed control. Praising participating landowners may be particularly effective because maintaining a positive reputation is a strong motivator toward cooperative behavior (Milinski et al. 2002). Collective factors could also be reinforced via multiple outreach channels such as face-to-face workshops that teach landowners control methods while reinforcing social norms surrounding weed control, reminding people about the cross-boundary nature of weeds, and inspiring increased trust and reciprocity among landowners and practitioners. Research has long shown that such interactions elevate the general, positive effect on cooperative behaviors (Ostrom 1990).

In Montana, and perhaps elsewhere, there is profound opportunity for outreach professionals to inspire weed control by engaging landowners around the collective nature of the weed problem. Incorporating collective messages into weed control outreach could reframe weed control as a moral good for the community, which may inspire landowners who currently see the problem as unsolvable to rethink their calculus, although further experimental research is needed. In this way, our results set the stage for randomized, controlled outreach experiments testing the effectiveness of collective factors for inspiring increased weed control, and opening the door to a host of novel weed control outreach methods.

Although our study illuminates the importance of collective factors in weed control, our results are limited by our cross-sectional design, which allowed us to correlate weed control with collective factors, but not determine causality. Application of these results to any specific weed species should be done with caution because some species can be viewed as beneficial (Marshall et al. 2011) while others as particularly harmful (Selge et al. 2011). Because of limited resources we were not able to conduct a more robust nonresponse check, so it remains possible that our respondents may be more apt to participate in collective action than nonrespondents. Our sample also consisted of a subset of Montana landowners based on land holding size and location who have unique perspectives on weed control that might not generalize to other landowners in the state, or elsewhere.

Overall, it remains clear that communication strategies seeking to inspire conservation behaviors on private land must be deliberate and evidence based (Urgeson et al. 2013, Amel et al. 2017, Drescher and Brenner 2018). Private landowners make many land management decisions autonomously, but they are clearly influenced by the behaviors and beliefs of those around them (Cialdini 2005, Amel et al. 2017). Conservation and stewardship efforts that consider the collective along with individual drivers of these decisions will better establish coordinated weed control efforts across ownership boundaries. These lessons likely apply not only to weeds, but extend to other private land conservation issues with collective dynamics such as wildlife habitat, watershed health, public access, and wildfire mitigation actions. Landowners ultimately make individual decisions to address even cross boundary problems, yet it is becoming increasingly clear that collective variables play a significant role in determining those choices.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/10897

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April 4, 2017

Dear Montana Landowner:

Last month we mailed you a survey about natural resource management on your property. You are one of a few Montana private landowners selected to participate in this study and your response will help natural resource management agencies across the state better design outreach programs for private landowners in Montana.

If you have already completed and returned this survey to us, please accept our sincere thanks. If not, please take some time to complete the survey and return it to us in the postage-paid envelope provided.

This survey asks about land management decisions relating to wildfire risk reduction, weed control and human-bear conflict reduction on private lands. In Montana, these three issues cross property boundaries and affect multiple landowners. Because these issues are widespread your input is valuable.

Your participation in this survey is completely voluntary and you may stop at any time or skip any question you do not wish to answer. All your answers will be anonymous – we will only report summaries of our findings. The identification number on the survey is there so we can check your name off the mailing list and save postage on future mailings.

It should take about 15-20 minutes to complete the survey. By completing and returning the questionnaire, you imply your consent to participate in this study. If you have any questions, do not hesitate to contact us.

Sincerely,

To complete the survey online! Go to:

Dr. Alexander L. Metcalf
Natural Resource Working Group
W. A. Franke College of Forestry and Conservation
alex.metcalf@umontana.edu
(406) 243-6673

Natural Resource Stewardship Survey
A survey to support Montana's private landowners

This survey has 4 sections with questions about your property, your interactions with people in your area, and your approach to three natural resource issues: wildfire, weeds, and human-bear conflict. We'd like to start by asking about your property and your reasons for owning.

1. Do you own more than 0.5 acres anywhere in the state of Montana? ☐ Yes ☐ No
   If no, please check the box and return the survey to us in the postage-paid envelope provided.

2. About how many total acres do you own in Montana? _____ *(acres)*

3. The following are some reasons why people own land. When you think about why you own your land, how important is each of the following reasons? Please use the 1 to 5 scale, where 1 is "Very Unimportant" and 5 is "Very Important."
   (*For each row, please circle only one number.*)

	Very Unimportant	Unimportant	Neither	Important	Very Important
Land investment (I hope to sell all or part of my land for a profit)	1	2	3	4	5
Personal use or recreation	1	2	3	4	5
General income (e.g., sale of timber, crops, cattle, leasing)	1	2	3	4	5
Solitude	1	2	3	4	5
Primary residence	1	2	3	4	5
To pass on to family members	1	2	3	4	5
Rural lifestyle	1	2	3	4	5

4. In your own words, please describe why you own your property. _____

_____

_____

_____

1

SECTION II – INVASIVE WEEDS

Weeds are any non-native, undesirable plant species. The following questions ask about weeds on your property and the actions that some landowners take to control weeds.

Weed Control on Your Property

12. How strongly do you agree or disagree with the following statements? Please use the 1 to 5 scale, where 1 is "Strongly Disagree" and 5 is "Strongly Agree." (*For each row, please circle only one number.*)

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
Weeds decrease my enjoyment of my property	1	2	3	4	5
Weeds decrease the economic value of my property	1	2	3	4	5
Weeds decrease the productivity of my property	1	2	3	4	5
Weeds negatively impact the appearance of my property	1	2	3	4	5
Weeds limit my ability to use my property in the ways I want	1	2	3	4	5

13. In your own words, please describe how weeds affect your ability to use your property in the ways you want, if applicable. _____

_____

_____

Weed Control Activities

14. How often do you take the following actions? (*For each row, please check only one box.*)

	Never	Sometimes	Always
Wash your personal gear/clothing after being in an area with weeds	☐	☐	☐
Wash your vehicle after being in an area with weeds	☐	☐	☐

Buy weed-free alternatives (weed free forage, weed free gravel)	☐	☐	☐
Check your property for weeds	☐	☐	☐

15. How strongly do you agree or disagree with the following statements? Please use the 1 to 5 scale, where 1 is "Strongly Disagree" and 5 is "Strongly Agree."
(*For each row, please circle only one number.*)

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
I have enough <u>money</u> to control weeds on my property	1	2	3	4	5
I have enough <u>time</u> to control weeds on my property	1	2	3	4	5
I am <u>confident</u> in my ability to identify weeds	1	2	3	4	5
I am <u>confident</u> I know how to effectively control weeds on my property	1	2	3	4	5
My personal actions can help control weeds on my property	1	2	3	4	5

16. Have you ever spoken with a weed professional (commercial applicator, MSU extension agent) or received educational material about controlling weeds?   ☐ Yes ☐ No
If yes, who or what was most helpful? _____

_____

_____

Weed Control in Your Area

17. How strongly do you agree or disagree with the following statements? Please use the 1 to 5 scale, where 1 is "Strongly Disagree" and 5 is "Strongly Agree."
(*For each row, please circle only one number.*)

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree

If you take actions to control weeds, neighboring property owners will notice or hear about it	1	2	3	4	5
If you take actions to reduce the spread of weeds, it will motivate neighboring property owners to take similar actions	1	2	3	4	5
If neighboring property owners take actions to reduce the spread of weeds, it will reduce the amount of weeds on my property as well	1	2	3	4	5
Together, neighboring property owners and I can effectively control weeds in our area	1	2	3	4	5

18. How satisfied or dissatisfied are you with the current efforts to control weeds in your area?
    (P*lease circle only <u>one</u> response.)*

Very Dissatisfied	Dissatisfied	Neither	Satisfied	Very Satisfied
1	2	3	4	5

19. Please answer the following "Yes" or "No" questions.
    (*For each row, please check only <u>one</u> box.)*

	Yes	No	Do Not Know
Has anyone ever asked you for your opinion on weed control?	☐	☐	
Has anyone ever tried to influence your opinion on weed control?	☐	☐	
Do most people in your area believe you should be taking steps to control weeds on your property?	☐	☐	☐
Do you believe most people in your area are taking actions to control weeds on their properties?	☐	☐	☐

SECTION IV – GENERAL QUESTIONS

The following questions ask about general activities, interactions with people in your area, opinions across several natural resource topics, and a few questions about your household.

27. How willing or unwilling are you to do the following activities? Please use the 1 to 5 scale, where 1 is "Very Unwilling" and 5 is "Very Willing."
    (*For each row, please circle only one number.*)

	Very Unwilling	Unwilling	Neither	Willing	Very Willing
Cut trees on your property	1	2	3	4	5
Contact your local fire department or other expert to request a wildfire home assessment	1	2	3	4	5
Work with an extension professional to develop a weed control plan for your property	1	2	3	4	5
Use herbicides to control weeds	1	2	3	4	5
Release bio-control (insects) to control weeds	1	2	3	4	5
Spend time pulling weeds from your property	1	2	3	4	5
Spend time pulling weeds along trails on public land	1	2	3	4	5
Apply for a government grant program to assist with management costs	1	2	3	4	5
Cooperate with your neighbors to conduct management	1	2	3	4	5
Work with a financial professional to establish an estate plan	1	2	3	4	5
Discuss your estate planning with your heirs/family	1	2	3	4	5

28. How strongly do you agree or disagree with the following statements? Please use the 1 to 5 scale, where 1 is "Strongly Disagree" and 5 is "Strongly Agree."
    (*For each row, please circle only one number.*)

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree

	Very Unlikely	Unlikely	Neither	Likely	Very Likely
I feel a strong sense of community with my neighbors	1	2	3	4	5
If there is a problem in my area, people here get it solved	1	2	3	4	5
I have an influence over what this community is like	1	2	3	4	5
I often take an active role in solving area problems	1	2	3	4	5

29. What groups in your area do you associate with or feel most welcomed by (neighborhood, church group, garden club, rotary, 4H)? _____

_____ 10

_____

_____

30. How likely or unlikely are you to use the following sources when you need information about how to manage or do something on your property. Please use the 1 to 5 scale, where 1 is "Very Unlikely" and 5 is "Very Likely."
(*For each row, please circle only one number.*)

	Very Unlikely	Unlikely	Neither	Likely	Very Likely
General internet search	1	2	3	4	5
Other landowners	1	2	3	4	5
MSU extension office	1	2	3	4	5
Weed district	1	2	3	4	5
State government (MT DNRC, Fish, Wildlife, & Parks)	1	2	3	4	5
Federal government (Forest Service; Bureau of Land Management)	1	2	3	4	5
Family or friends	1	2	3	4	5
Local businesses	1	2	3	4	5
Professional advisor/consultant	1	2	3	4	5

Neighborhood network	1	2	3	4	5
Community wildfire preparedness group	1	2	3	4	5
Workshops or classes	1	2	3	4	5
Brochures or other printed material	1	2	3	4	5

31. How strongly do you agree or disagree with the following statements? Please use the 1 to 5 scale, where 1 is "Strongly Disagree" and 5 is "Strongly Agree."
(*For each row, please circle only one number.*)

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
Economic growth should be given priority, even if the environment suffers	1	2	3	4	5
The balance of nature is delicate and easily upset	1	2	3	4	5
I see my land as self-contained – I don't think much about the surrounding land	1	2	3	4	5
I trust the government to manage wildfire risk	1	2	3	4	5
I trust the government to control weeds	1	2	3	4	5
I trust the government to reduce human-bear conflict	1	2	3	4	5

32. How many children and/or dependents do you have living at home? _____

33. Do you plan to leave your land to any heirs (e.g., children, dependents, relatives)?
☐ No ☐ Yes   If yes, how many?_____(number of heirs)

34. What is the highest grade of school you completed? (*Please check only one box.*)

☐ Grade school ☐ High school/GED ☐ Some college ☐ College graduate ☐ Post graduate

35. What is your gender?   ☐   Male   ☐   Female   ☐   Prefer not to answer

36. What year were you born? _____ (*year*)

37. How long have you owned your property in Montana? _____ (*years*)

38. What is your approximate annual household income before taxes (optional)?
    (*Please check only <u>one</u> box.*)

☐ Less than $9,999   ☐ 10,000 to $19,999   ☐ $20,000 to $39,999
☐ $40,000 to $59,999   ☐ $60,000 to $79,999   ☐ $80,000 to $99,999
☐ $100,000 to $119,999 ☐ $120,000 to $139,999 ☐ $140,000 or more
☐ Refuse to disclose or don't know

Thank you for taking this survey. If you have any comments, please include them in the space below:

_____

_____