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Article *in* Environmental Management · December 2019

DOI: 10.1007/s00267-019-01238-8

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Practitioner Insights into Weed Management on California's Rangelands and Natural Areas

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Received: 6 May 2019 / Accepted: 26 November 2019

Abstract

Working rangelands and natural areas span diverse ecosystems and face both ecological and economic threats from weed invasion. Restoration practitioners and land managers hold a voluminous cache of place-based weed management experience and knowledge that has largely been untapped by the research community. We surveyed 260 California rangeland managers and restoration practitioners to investigate invasive and weedy species of concern, land management goals, perceived effectiveness of existing practices (i.e., prescribed fire, grazing, herbicide use, and seeding), and barriers to practice implementation. Respondents identified 196 problematic plants, with yellow starthistle (*Centaurea solstitialis* L.) and medusahead (*Elymus caput-medusae* L.) most commonly listed. Reported adoption and effectiveness of weed management practices varied regionally, but the most highly rated practice in general was herbicide use; however, respondents identified considerable challenges including nontarget effects, cost, and public perception. Livestock forage production was the most commonly reported management goals (64% of respondents), and 25% of respondents were interested in additional information on using grazing to manage invasive and weedy species; however, 19% of respondents who had used grazing for weed management did not perceive it to be an effective tool. Across management practices, we also found common barriers to implementation, including operational barriers (e.g., permitting, water availability), potential adverse impacts, actual effectiveness, and public perception. Land manager and practitioner identified commonalities of primary weeds, management goals, perceived practice effectiveness, and implementation barriers across diverse bioregions highlight major needs that could be immediately addressed through management–science partnerships across the state's expansive rangelands and natural areas.

Keywords Invasive plants · Livestock grazing · Herbicide · Seeding · Prescribed fire · California

Introduction

Working rangelands and natural areas span diverse ecosystems around the globe, representing a majority of the world's land resources (Lund 2007; Kettenring and Adams 2011). These systems, which include privately and publicly managed lands, cover ~64% of the United States (US) (U.S. Department of Agriculture 2018) and are highly valued for their environmental goods and services (Havstad et al. 2007; Brunson and Huntsinger 2008; Roche et al. 2015b). The spread of weedy and invasive plants is a major threat to these systems with impacts including both economic losses (e.g., reduced quantity and quality of livestock forage) and environmental degradation (e.g., depleted soil and water resources, altered fire regimes, and reduced plant diversity) (DiTomaso 2000; Vilà et al. 2011; Gornish et al. 2018). Across managed and natural systems in the US, the total costs of weedy and invasive plants has been variously estimated from US$13 to 27 billion annually (Westbrooks 1998; Pimentel et al. 2005). For these reasons, rangelands and natural areas are a major focus of conservation and restoration management and policy efforts.

Supplementary information The online version of this article (https://doi.org/10.1007/s00267-019-01238-8) contains supplementary material, which is available to authorized users.

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Published online: 14 December 2019

An extensive body of biophysical research literature has focused on individual control practices and integrated weed management strategies for working rangelands and natural areas (James et al. 2015). Integrated weed management strategies are broadly termed Integrated Pest Management (IPM), which is an adaptive, ecosystem-based approach to pest and weed control that uses a combination of mutually supportive treatments. Common IPM methods used for controlling invasive and weedy plants on working rangelands and natural areas include targeted livestock grazing, mechanical treatment, herbicide application, and prescribed burning. Plot- and field-based studies have demonstrated that integrated control methods can reduce weed seedbanks, decrease seedling density of common invasive weeds, reduce reliance on chemical control, and improve plant community diversity (Ditomaso et al. 1999; DiTomaso 2000; Daehler and Goergen 2005; Gornish et al. 2018); however, there is relatively limited research on effectiveness of management-scale implementation of these practices.

Restoration practitioners and land managers hold a largely untapped cache of place-based weed management knowledge and experience that is often orders of magnitude greater in spatial coverage and duration than typical research conditions. Management strategies are also often adapted over time, through trial-and-error problem solving, in response to on-the-ground challenges. Therefore, directly deriving management information from experienced practitioners and land managers can greatly increase our ability to understand factors contributing to successes and failures, as well as strengthen linkages between research and field applications (Roche et al. 2015a, 2015b). Also, identifying practitioner's underlying goals, management practices, and primary challenges can provide insight into key factors shaping decision-making, which can aid future efforts for controlling weedy and invasive plants as well as guide research priorities (Wilson et al. 2008; Roche et al. 2015b). For example, perceptions of peer attitudes, risks, and benefits can affect adoption of landscape management strategies (Didier et al. 2004; Norgaard 2007; Lubell et al. 2013).

We conducted a social survey of land managers and restoration practitioners across California to collect and synthesize on-the-ground perspectives on invasive and weedy plant management for working rangelands and natural areas. These systems have long been dominated by a largely exotic, annual flora (Schiffman 2007) that both public and private land managers have worked to manage for a multitude of agricultural and environmental goals. The objectives of this paper are to document the following: (1) weed management experience and priorities of California land managers and restoration practitioners; and (2) adoption and perceived effectiveness of weed management practices. This work will provide guidance for research, management, and policy communities in identifying critical gaps in research and outreach education as well as priorities for identifying sustainable and economic approaches to weed control.

Methods

We developed a survey (Supplementary 1) for land managers and practitioners, which we distributed at a series of seven extension education workshops across California. We advertised workshops via local cooperative extension and professional networks to reach a broad range of public and private land managers with potential interests in invasive plants and weed issues. The workshops featured presentations highlighting locally relevant information and recent developments in weed management research and applications. The survey included sections on respondents' on-the-ground experience, weed management perspectives and priorities, and management information needs. Survey questions were developed and pilot tested with management professionals. The final survey was administered at each workshop. A total of 306 participants attended the seven extension education workshops, with 260 completed surveys (84.6% response rate) eligible for this analysis. This survey approach has the potential to create a biased sample of respondents as those with greater interest in weed management and connecting with academic research institutions would be more likely to participate; however, despite this potential bias, this approach did directly engage a broad range of practitioners and managers representing significant land area across California. This study was approved by the University of California, Davis Institutional Review Board protocol 784586-1.

Here, we use descriptive statistics to characterize survey and interview respondent experiences, management priorities and practices, and information resources. The number of responses (n) per question varied and is noted throughout. For open-ended questions, we used an iterative coding process of summarizing and organizing respondent answers (Neuman 2003; Fernandez-Gimenez and Knapp 2009). We then computed the number of individually coded responses under each theme and the number of respondents addressing each theme.

Results

Land Manager and Practitioner Demographics

Survey respondents included local, state, and federal natural resources management agency personnel ($n = 121$), environmental and agricultural nongovernment organization

personnel ($n = 34$), university academics and affiliates ($n = 20$), and private business practitioners and landowners ($n = 106$). Eight percent of respondents indicated more than one organization affiliation. Respondents also identified their individual roles, including land manager ($n = 126$), management advisor ($n = 82$), landowner ($n = 56$), rancher ($n = 55$), business owner ($n = 38$), and researcher ($n = 16$). The majority (70%) indicated one role, while 13% identified two roles and 17% identified three or more roles ($n = 248$).

Survey respondents ($n = 256$) represented perspectives across a diversity of bioregions in California, and 25% of the respondents worked in more than one region. In terms of experience, 40% had more than 15 years, 29% had 6–15 years, 27% had 1–5 years, and 4% had less than 1 year of experience ($n = 255$; range of experience was <1 month to 64 years). In total, respondents ($n = 169$) reported management and decision-making authority for 10.3 million ha (mean response of 1012 ha, range of <1 to 2.4 million ha overseen). The majority of respondents had considerable influence or were primary decision makers in weed management decisions (63%; $n = 259$). Twenty-six percent of respondents reported some influence and 11% reported little to no influence on weed management decision-making.

Management Goals

Respondents ($n = 251$) identified two priority management goals—forage production for grazing livestock (64%) and conservation and habitat management (53%); 27% of respondents identified both forage production and conservation and habitat management as priority goals. Additional goals included other agricultural production (22%) and parks/recreation (13%). Approximately 56% of respondents identified one main goal, 42% identified two to three main goals, and 2% identified four or more main land management goals. More than two-thirds of respondents (70%) identified weed management as a high to essential priority in their organizational roles ($n = 260$). The most commonly noted problematic weeds were yellow starthistle (*Centaurea solstitialis* L.) and medusahead (*Elymus caput-medusae* L.); 40% of respondents listed medusahead and 38% listed yellow starthistle as one of their top three most problematic weeds ($n = 252$). For priority rankings, 20% of respondents identified yellow starthistle as their number one most problematic weed and 12% identified medusahead as their number two most problematic weed ($n = 252$). Identity and ranking of the most problematic weeds varied by bioregion, but medusahead was the most commonly identified species among the top three problematic weeds for all areas (Li et al., in review). Of the respondents who indicated both forage production and conservation and habitat management as priority goals, 52% listed medusahead as one of their top three most problematic weeds and 42% listed yellow starthistle ($n = 69$). Of the respondents indicating conservation and habitat management but not forage production as a priority goal, 46% listed yellow starthistle as one of their top three most problematic weeds and 26% listed medusahead ($n = 61$). Finally, of the respondents indicating forage production but not conservation and habitat management as a priority goal, 43% listed medusahead as one of their top three most problematic weeds and 35% listed yellow starthistle ($n = 93$). In total, respondents listed 196 problematic weeds that ranged in level of identification from general (e.g., "annual grasses" and "thistles") to specific species names.

Less than 34% of respondents reported cost information associated with weed management. A total of US$11.3 million annual costs for weed management was reported by 88 respondents. Median expenditures on weed control were US$600, with a range of US$0–5 million. Median proportion of operating budget allocated to weed control was reported at 2% ($n = 71$; range of 0–100%).

Adoption and Perceived Effectiveness of Weed Management Practices

Respondents' ($n = 214$) most common strategies for managing weeds fell into the following three observable tiers: (1) herbicide or chemical control (57%); (2) mechanical (e.g., mowing, disking, and hand pulling) (39%) and livestock grazing (e.g., cattle, sheep, and goats) (32%); and (3) other, which was comprised of seeding (9%), and burning (4%). The majority (71%; $n = 235$) of respondents reported using IPM strategies.

We also asked respondents about their frequency of use (1–5 scale, from "never" to "always") and, if used, perceived effectiveness (1–5 scale, from "very poor" to "excellent") of four common weed management practices: prescribed fire, livestock grazing, herbicide use, and seeding (Tables 1 and 2). For those with previous experience, herbicide use received the highest ranking for effectiveness (median rank of 4 and mean rank of 3.7; $n = 208$) with only 2% of respondents reporting poor to very poor success. The most commonly listed herbicides used were glyphosate (50%; $n = 187$; combined responses for "glyphosate" and "Roundup," tradename for a glyphosate-based herbicide), "Milestone" (19%; $n = 187$; tradename for an aminopyralid-based herbicide), and "Transline" (5%; $n = 187$; tradename for a clopyralid-based herbicide). Respondents reported less success using livestock grazing (median rank of 3, mean rank of 3.1, and 19% poor to very poor success; $n = 185$), seeding (median rank of 3, mean rank of 2.9, and 24% poor to very poor success; $n = 153$), and prescribed fire (median rank of 3, mean rank of 3.0, and 27% poor to very poor success; $n = 110$) for their weed management goals (Table 2).

Table 1 Summary of survey respondents' reported use of weed management practices

Practice	Workshop location					
	North Coast	Northeast	Sacramento Valley	San Joaquin Valley	Central Coast	South Coast
Prescribed fire						
Never (%)	69.4	45.5	39.7	61.5	65.9	50.0
Rarely (%)	27.8	42.4	35.6	23.1	27.3	31.3
Sometimes (%)	2.8	12.1	17.8	15.4	6.8	18.8
Often (%)	0	0	6.8	0	0	0
Always (%)	0	0	0	0	0	0
n[a]	36	33	73	26	44	32
Livestock grazing						
Never (%)	38.9	9.1	12.7	22.2	27.9	15.6
Rarely (%)	5.6	18.2	7.0	14.8	7.0	9.4
Sometimes (%)	19.4	33.3	28.2	33.3	23.3	18.8
Often (%)	16.7	36.4	33.8	22.2	27.9	25.0
Always (%)	19.4	3.0	18.3	7.4	14.0	31.3
n	36	33	71	27	43	32
Herbicides						
Never (%)	16.7	12.1	8.6	8.0	13.6	15.6
Rarely (%)	22.2	15.2	10.0	16.0	18.2	9.4
Sometimes (%)	22.2	9.1	34.3	20.0	22.7	40.6
Often (%)	30.6	48.5	38.6	44.0	34.1	28.1
Always (%)	8.3	15.2	8.6	12.0	11.4	6.3
n	36	33	70	25	44	32
Seeding						
Never (%)	28.6	24.2	18.6	48.0	37.2	51.5
Rarely (%)	11.4	33.3	22.9	32.0	14.0	21.2
Sometimes (%)	25.7	30.3	31.4	12.0	39.5	21.2
Often (%)	22.9	12.1	18.6	8.0	9.3	6.1
Always (%)	11.4	0	8.6	0	0	0
n	35	33	70	25	43	33

[a]Number of respondents for each workshop by practice combination

To understand barriers to adoption, we asked survey participants to describe their main concerns in applying specific practices (prescribed fire, grazing, herbicide use, and seeding). Respondents were able to note multiple concerns. Respondents identified several common barriers to implementation across practices. Operational barriers were identified for prescribed fire (68% of respondents noted permitting issues; $n = 239$), livestock grazing (27% noted water availability issues and 25% noted a lack of access to animals; $n = 227$), and seeding (30% noted water availability issues; $n = 227$). Respondents identified potential adverse impacts of using prescribed fire (liability/safety concerns; 47%), grazing (exposure to unpalatable/toxic plants; 42%), and herbicides (59% noted potential effects on nontarget plants; $n = 227$). Concerns regarding actual effectiveness of practices were noted for both grazing (40%) and seeding (57%). Lastly, respondents identified concerns about public perception in using prescribed fire (39%) and herbicides (34%) to control invasive and weedy species. Primary concerns identified for weed management practices were similar across bioregions. We also asked respondents "what weed management approaches would you like to know more about?" (open-ended question with 43% of respondents listing multiple topics). We found most respondents were interested in grazing management (e.g., prescribed grazing; 44 mentions out of 261 total mentions from 178 respondents; 17% of mentions), herbicide selection and use (39 mentions; 15% of mentions), IPM strategies (33 mentions; 13% of mentions), cultural practices (e.g., seeding and fertilization) (28 mentions; 11% of mentions), and prescribed fire (26 mentions; 10% of mentions) (Fig. 1).

Table 2 Summary of survey respondents' perceived effectiveness of weed management practices

Practice	Workshop location					
	North Coast	Northeast	Sacramento Valley	San Joaquin Valley	Central Coast	South Coast
Prescribed fire						
Very poor (%)	12.5	11.1	4.7	10.0	0	6.7
Poor (%)	12.5	27.8	14.0	30.0	30.8	33.3
Fair (%)	25.0	27.8	46.5	50.0	61.5	33.3
Good (%)	12.5	33.3	27.9	0	7.7	20.0
Excellent (%)	37.5	0	7.0	10.0	0	6.7
n[a]	8	18	43	10	13	15
Livestock grazing						
Very poor (%)	5.0	8.0	0	10.0	3.3	3.8
Poor (%)	10.0	24.0	21.4	25.0	10.0	7.7
Fair (%)	50.0	36.0	62.5	45.0	43.3	57.7
Good (%)	30.0	32.0	14.3	15.0	40.0	23.1
Excellent (%)	5.0	0	1.8	5.0	3.3	7.7
n	20	25	56	20	30	26
Herbicides						
Very poor (%)	0	0	0	0	0	0
Poor (%)	3.4	0	3.3	0	5.6	0
Fair (%)	31.0	42.3	31.7	33.3	27.8	32.0
Good (%)	62.1	50.0	53.3	54.2	52.8	60.0
Excellent (%)	3.4	7.7	11.7	12.5	13.9	8.0
n	29	26	60	24	36	25
Seeding						
Very poor (%)	8.0	5.0	5.5	9.1	4.0	7.1
Poor (%)	24.0	50.0	21.8	36.4	32.0	14.3
Fair (%)	40.0	35.0	43.6	18.2	40.0	50.0
Good (%)	24.0	10.0	25.5	27.3	16.0	28.6
Excellent (%)	4.0	0	3.6	9.1	8.0	0
n	25	20	55	11	25	14

[a]Number of respondents for each workshop by practice combination

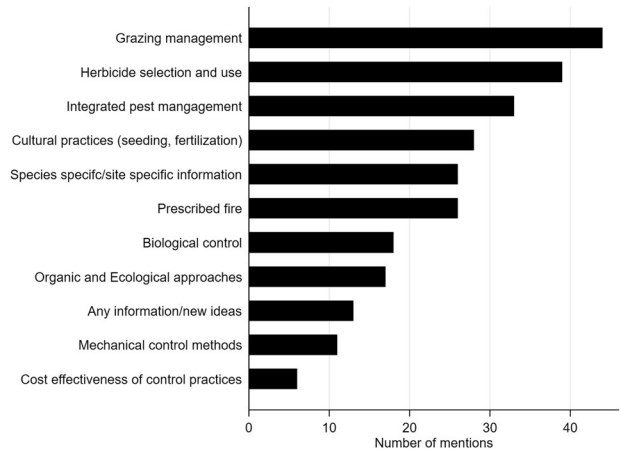

Fig. 1 Survey respondent responses (261 mentions from 178 respondents) to the questions, "What weed management strategies would you like to know more about?"

Discussion

Invasive weeds can have dramatic ecological and economic impacts on rangelands and natural areas. Our survey results capture the priorities and practices of land managers and restoration practitioners who manage invasive weeds on public and private lands across California's diverse bioregions. The survey derives information from 10.3 million ha, ~1 quarter of California's total land area. Managers and practitioners shared their perspectives on the most problematic weeds, effective management strategies, and barriers to implementation. By engaging stakeholders who have decades of on-the-ground experience with invasive species issues across inherently variable and complex landscapes, we can leverage a largely untapped resource of knowledge to identify weed research priorities and improve adoption and use of effective practices.

Respondents' most commonly listed priority invasive and weedy species were not unexpected. Yellow starthistle has been estimated to invade over 5.7 million ha in California (Pitcairn et al. 2006), and medusahead is known to be rapidly spreading across the west (Duncan et al. 2004); however, the large number of problematic weeds identified highlights the complexity of challenges that land managers and restoration practitioners face across the state. These challenges can be further exacerbated by inherently decentralized management in which multiple decision makers are managing different portions of an invasive species population (Coutts et al. 2013). For example, due to differences in risk perceptions (Norgaard 2007), the way invasive species are managed can differ among individuals. Differences in priority goals, such as we found when comparing respondents' managing for grazing forage versus those managing for habitat conservation, can also lead to different perceptions in primary weed issues.

Resulting patchworks in management approaches across a landscape might actually result in broader infestations—even with a small number of managers not implementing control strategies (Coutts et al. 2013).

Survey respondents identified two main themes of management goals—grazing and forage production and conservation/habitat management. For those who noted grazing/forage production as a main goal, many also emphasized supporting conservation and habitat goals as well. Previous work has suggested that when looking to advance conservation goals on working rangelands, there should be a focus on solutions for both economic and ecological sustainability (Roche et al. 2015b; Eastburn et al. 2018). Traditional weed management research has commonly focused on a singular goal—reducing invasive species populations. This work shows that land managers are, by necessity, not single goal focused; in fact, land managers and restoration practitioners are balancing weed control decisions with a multitude of ecological, agricultural, social, and economic drivers (Table 3). Applied research that directly addresses multiple management goals would provide practitioners with techniques and approaches that are immediately relevant for on-the-ground weed control.

Grazing and forage production were identified as primary goals; however, livestock grazing to specifically manage for weeds was found to be a relatively ineffective strategy by many (Table 2). The perceived ineffectiveness could be due to lack of knowledge and experience in specifically implementing livestock grazing as a tool, especially given observed respondent interests in additional information on grazing management for weed control (Fig. 1). In addition, there are limitations to translating fine-scale, controlled experiments (Roche et al. 2015a) for effective implementation in complex management scenarios (DiTomaso et al. 2008; Rinella and Bellows 2016). In fact, there is a rapidly growing movement to better align research with on-the-ground needs and application, with recent work highlighting disconnects between short term, plot-scale research and the longer temporal and larger spatial scales at which land managers work (Roche et al. 2015a; Derner et al. 2018; Swart et al. 2018). For example, a review of the scientific literature on grazing strategies revealed that median pasture area and median total study area were two orders of magnitude smaller than the median reported grazing area on ranching operations (Roche et al. 2015a).

Respondents' reported on-the-ground experiences with seeding for weed control (Tables 2 and 3) aligns with recent, management-scale experimental results demonstrating limited success and high costs of rangeland seeding (Eastburn et al. 2018). One way to address this challenge of seeding for weed control would be to implement more proactive strategies that inhibit initial invasion and restrict weed population expansion. This could include adoption of hedgerows on grassland peripheries, which has demonstrated success in farming (e.g., Brodt et al. 2009), and deployment of greenstrips (Porensky et al. 2018).

Addressing barriers to successful on-the-ground management are critical to controlling invasive species, particularly given the vast area of influence held by land managers and restoration practitioners. Similar to other surveys, we found cost-effectiveness and knowledge gaps to be primary barriers to weedy and invasive plant management (Wilson et al. 2008; Alexander et al. 2017). Survey results additionally revealed social barriers to practice implementation. While the majority of respondents found

Table 3 Summary of survey respondents' top three concerns for using specific weed management practices

Practice	No. 1 concern	No. 2 concern	No. 3 concern
Prescribed fire ($n^a = 239$)	Permitting (68%)[b]	Losing control of fire (47%)	Public perception (39%)
Livestock grazing ($n = 227$)	Poor palatability or toxic weeds (42%)	Ineffective weed control (40%)	Water availability (27%)
Herbicides ($n = 241$)	Effects on nontarget plants (59%)	Cost (42%)	Public perception (34%)
Seeding ($n = 214$)	Cost (67%)	Poor establishment (57%)	Water availability (30%)

[a]Total number of respondents reporting for each practice

[b]Percentage of total respondents for each practice reporting given concern

herbicides to be the most effective weed management tool, nearly half mentioned public perception as a major concern (Table 3). This will likely continue to be a significant management and policy consideration given growing public debate on the use of chemical weed control (Hawkes and Stiles 1986; Norgaard 2007) and the growing number of herbicide-resistant weeds worldwide (Heap 1997). Our survey results also highlighted training and extension education needs for herbicide use and application as most respondents reported concerns about herbicide effects on nontarget plants but were primarily using a broad-spectrum herbicide. The high number of respondents employing an IPM approach to weed control also suggests that managers are considering techniques that might not require herbicide use (Powels and Matthews 1992; but see Epstein and Zhang 2014).

The large number of invasive and weedy species of concern, identified barriers, and interest in additional information on practices among land managers and restoration practitioners highlights the complex nature of weed management. Despite this complexity and the diversity of bioregions surveyed in this effort, we still found commonalities in the primary weeds identified, priority management goals, perceived effectiveness of weed management practices (e.g., herbicides and seeding), and implementation barriers. These common needs present an opportunity to strategically target research and outreach efforts to provide broad benefits across the state's extensive rangelands and natural areas. To provide the most relevant outcomes, the scientific and management communities must work together to codevelop and test strategies (e.g., using an adaptive management framework) at spatial and temporal scales relevant to management on inherently variable and complex landscapes, such as rangelands and natural areas.

Acknowledgements Funding was provided in part via the California Department of Pesticide Regulation (DPR). The contents of this document do not necessarily reflect the views and policies of DPR, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. We are thankful to the project technicians and interns who helped with data collection and entry, as well as our survey beta testers. We appreciate project workshop sponsor support from Alligare, California Beef Cattle Improvement Association, California Invasive Plant Council, California Native Grasslands Association, Dow AgroSciences, and USDA Natural Resources Conservation Service. We are also grateful to the local University of California Cooperative Extension advisors who assisted with hosting the workshop series Morgan Doran, David Lile, Rebecca Ozeran, Devii Rao, Matthew Shapero, and Jeff Stackhouse. Lastly, we owe a debt of gratitude to all of the workshop, survey, and interview participants who willingly shared their knowledge and time with us.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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