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Research article

Private land manager capacity to conserve threatened communities under climate change

C.M. Raymond [a, b, *], A.M. Lechner [c, d], M. Lockwood [e], O. Carter [f], R.M.B. Harris [g], L. Gilfedder [f]

[a] *Geosciences and Natural Resource Management, University of Copenhagen, Rolighedsvej 23, Frederiksberg, Denmark*
[b] *Enviroconnect, PO Box 190, Stirling, South Australia 5152, Australia*
[c] *Centre for Environment, University of Tasmania, Private Bag 141, Hobart, Tasmania 7001, Australia*
[d] *Centre for Social Responsibility in Mining, Sustainable Minerals Institute, Sir James Foots Building (47A), Staff House Road, The University of Queensland, Brisbane, Queensland 4072, Australia*
[e] *Geography and Spatial Sciences, School of Land and Food, University of Tasmania, Private Bag 78, Hobart, Tasmania 7001, Australia*
[f] *Natural and Cultural Heritage Division, Department of Primary Industries, Parks, Water and Environment, PO Box 44, Hobart, Tasmania 7001, Australia*
[g] *Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), University of Tasmania, Private Bag 80, Hobart, Tasmania 7000, Australia*

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ABSTRACT

Major global changes in vegetation community distributions and ecosystem processes are expected as a result of climate change. In agricultural regions with a predominance of private land, biodiversity outcomes will depend on the adaptive capacity of individual land managers, as well as their willingness to engage with conservation programs and actions. Understanding adaptive capacity of landholders is critical for assessing future prospects for biodiversity conservation in privately owned agricultural landscapes globally, given projected climate change. This paper is the first to develop and apply a set of statistical methods (correlation and bionomial regression analyses) for combining social data on land manager adaptive capacity and factors associated with conservation program participation with biophysical data describing the current and projected-future distribution of climate suitable for vegetation communities. We apply these methods to the Tasmanian Midlands region of Tasmania, Australia and discuss the implications of the modelled results on conservation program strategy design in other contexts. We find that the integrated results can be used by environmental management organisations to design community engagement programs, and to tailor their messages to land managers with different capacity types and information behaviours. We encourage environmental agencies to target high capacity land managers by diffusing climate change and grassland management information through well respected conservation NGOs and farm system groups, and engage low capacity land managers via formalized mentoring programs.

1. Introduction

Climate change is projected to be a dominant driver of species extinctions and distribution shifts over the 21st century, exacerbated by land-use change (Pereira et al., 2010). As climate conditions diverge from those under which current ecosystems adapted, the composition and structure of ecological communities are also expected to change, potentially leading to establishment of degraded, or even novel ecosystems for which there are no current analogues (Folke et al., 2010; Starzomski, 2013). In North America, vegetation composition and dynamics have been strongly influenced by combinations of human land management and altered disturbance regimes such as fire (Nowacki and Abrams, 2014; Thébault et al., 2014). However, climatic change may affect the dynamics and balance of different vegetation communities, including the potential for range contraction of native grasslands and expansion of invasive species (Polley et al., 2013; Prevéy and Seastedt, 2014). The influence of climate change on grassland community dynamics in Europe is less clear. Recent modelling of twelve grassland sites in France suggests a move towards more arid climates by the end of the century, and new opportunities for

* Corresponding author. PO Box 190, Stirling, South Australia 5152, Australia.
E-mail address: chris.raymond@enviroconnect.com.au (C.M. Raymond).

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annual and seasonal herbage production in spring and winter (Graux et al., 2013).

Temperate grassy eucalypt woodlands and grasslands in south-eastern Australia are likely to be particularly affected by changing climatic conditions (Prober et al., 2012). In their study of the projected effects of climate change on these grasslands and closely related vegetation communities, Harris et al. (2015) concluded that attempting to maintain the status quo by conserving the current structure and composition is unlikely to be a viable management option in the future. They pointed out that measures such as long-term conservation covenants with fixed boundaries, and protection under environmental legislation that sets thresholds based on historical floristic composition, have not accounted for the potential development of novel grassy vegetation communities under climate change.

Given the prospect of major global changes in the vegetation community distributions and in ecosystem processes, it is desirable that land managers have the capacity and resources to minimise degrading impacts. In this paper, we focus on the contribution that private land managers, by which we mean the managers of lands under private tenure, can make to achieving biodiversity outcomes on their properties. In agricultural regions, a significant proportion of threatened communities tend to be located on land managed by individual private land owners. In North America, Europe and Australasia, private land tenure constrains the regulatory power of governments so that unilateral acquisition of private land for conservation purposes is either unlawful or highly unlikely. In Australia, governments and conservation non-government organisations (NGOs) have applied multiple policy instruments and nature conservation strategies to augment regulatory responses, including capacity building, education, management agreements, conservation covenants and economic incentives to improve nature conservation on private land (Stoneham et al., 2000; Curtis et al., 2014; Fitzsimons and Carr, 2014).

The effectiveness of conservation policy instruments and mechanisms can be enhanced if their selection and design is informed by an understanding of land manager adaptive capacity (Moon and Cocklin, 2011; Sorice et al., 2011). Adaptive capacity is the ability for individuals, communities or institutions to respond to change (Folke et al., 2005). Under climate change, the adaptive capacity of land managers is expected to be of particular importance (Smit and Wandel, 2006). Understanding the influence of adaptive capacity on uptake of conservation actions or instruments will be useful in future engagement of private land managers by governments and NGOs working to secure conservation outcomes under a changing climate. Adaptive capacity may be expressed through actions that maintain a desired state, or lead to a favourable transformation when the current state is untenable or undesirable (Folke et al., 2005; Gupta et al., 2010; Engle, 2011). The adaptive capacity of private land managers is comprised of their social capital, human, financial and physical capital, and management approaches (Lockwood et al., 2015).

In the context of land management, social capital refers to managers' social networks (both local and non-local), partnership agreements with environmental agencies and conservation non-government organisations, and flows of information (Adger et al., 2005). Aspects of social capital that are particularly implicated in adaptive capacity are trust, reciprocity and networks (Adger, 2003; Armitage, 2005; Folke et al., 2005; Pelling and High, 2005). Land managers with high trust in government and NGOs, who reciprocate knowledge and skills with neighbours, and have strong social networks are likely to have stronger capacity to adapt to a changing climate than those without these characteristics (Lockwood et al., 2015). Social capital infers collaboration and cooperation between land managers and conservation-relevant stakeholders in times of stress, and implies the effective delivery of management effort to cope with threats to resources and resource users (Adger, 2003; Adger and Vincent, 2005).

The adaptive capacity of land managers is informed by their human capital in terms of knowledge and access to information, access to labour, and willingness and capacity to devote time to thinking through and acting on change management strategies (Gupta et al., 2010; Nelson et al., 2010). Availability of supporting financial capital to enable access to learning opportunities and to support implementation of conservation actions, as well as physical capital including management-related infrastructure, are also important (Yohe and Tol, 2002; Pahl-Wostl, 2009; Engle and Lemos, 2010; Nelson et al., 2010). In addition, adaptive capacity depends on the land manager's approach to management, which is influenced by attitudes to risk, uncertainty and innovation, as well as willingness to seek out information and embrace an adaptive management approach (Ivey et al., 2004; Tompkins and Adger, 2005). Adaptive management recognises that uncertainty and incomplete knowledge are inevitable, and that there are benefits to embracing experimentation, innovation and learning (Allan and Curtis, 2005).

In addition to adaptive capacity, it is useful to consider land managers' receptiveness to involvement in long-term conservation management when designing future engagement strategies and programs. Land managers with a long duration of property ownership, large property size, extensive area of native vegetation, and past program participation are more likely to become engaged in both formal and informal forms of conservation management (Crase and Maybery, 2004; Bohnet, 2008; Seabrook et al., 2008; Morrison et al., 2011). However, the relationships between grassland distribution, adaptive capacity and conservation program participation remain largely unknown globally. Examining the relationships between the distributions of native vegetation communities, adaptive capacity and conservation program participation will improve understanding of the capacity of land managers (of all types) to anticipate and cope with change, given their existing resources and approaches. With such knowledge, governments and conservation NGOs can devise conservation instruments, strategies and programs that are more likely to produce good conservation outcomes from the perspective of environmental agencies.

A growing conservation opportunity literature indicates that environmental management policies and plans are more likely to be implemented if they consider dimensions of conservation priority, including conservation value, alongside aspects of feasibility of policy or plan implementation, including economic cost of conservation efforts, adaptive capacity, land manager willingness to engage in conservation programs, and land manager socio-demographic and farm characteristics (Knight et al., 2006; Naidoo et al., 2006; Raymond and Brown, 2011; Ban et al., 2013; Mills et al., 2013; Pressey et al., 2013). While a recent special section of *Conservation Biology* sheds light on theories, methods and processes for integrating spatially referenced biological and social data to inform community engagement programs (see Raymond, 2014 for an overview), we are not aware of any works which have systematically integrated measures of the distribution of threatened communities (an indicator of conservation priority) with aspects of management feasibility to inform the selection and design of community engagement programs. Such a line of questioning should help tailor engagement approaches to increase the range of land managers and conservation science organisations involved in conservation planning in the 21st century (Foster et al., 2014).

The aim of this paper is to demonstrate how integration of data on (i) land manager adaptive capacities and factors associated with conservation program participation; (ii) vegetation communities;

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and (iii) current and future climate envelopes can inform the design and application of community engagement programs. Our study area was the Midlands of Tasmania in southern Australia, with a particular focus on threatened lowland native-grassland vegetation. We explore associations between native grassland cover (both current extent and projected climatic envelopes) and the capacity of land managers to adaptively manage grassland ecosystems. We develop a binomial logistic regression model, to understand how land manager adaptive capacity, socio-demographic factors and property characteristics influence self-reported participation in conservation programs designed to support the conservation of native grasslands. Implications of our analysis are discussed, both for our case study and for conservation in other privately-owned landscapes where biodiversity is projected to be influenced by climate change.

2. Methods

We focus on private properties that are larger than two hectares and are located in the Northern Midlands Bioregion in Tasmania, Australia (hereafter the Tasmanian Midlands). We draw upon three sets of data: (i) social data relating to self-reported capacity to manage grasslands, socio-demographic and property characteristics and participation in conservation programs; (ii) vegetation mapping of the current extent of lowland native grasslands in the Tasmanian Midlands (DPIPWE, 2013); and (iii) projected future climate envelopes of lowland native grassland as identified by Harris et al., (2015).

2.1. Study area and grassland management policy context

The Tasmanian Midlands agricultural region is a flat, low-lying basin located in central northern Tasmania with an area of approximately 4000 km^2. There is a very small population base in this rural region. In 2011, the Tasmanian Midlands total population was 4709 (<1% of the State's population of 489,029). There are several rural towns in the region, the largest being Campbell Town, with a population of approximately 800 (Gadsby et al., 2013). The region was one of Australia's first to be converted to agriculture and was largely freehold by the 1830s. The largest enterprises in the region are grazing of sheep for wool and meat, and cattle for meat, with recent diversification into crops such as peas, cereal, potato and poppies. The construction of the Midlands Irrigation Scheme was recently completed, leading to a potential expansion of irrigated agriculture for new land uses such as dairy and horticulture.

In 2003 the Tasmanian Midlands was designated a Biodiversity Hotspot by the Australian Government, one of fifteen in Australia (Department of the Environment, 2014). It was described as a region with significant biodiversity loss, containing a high richness of threatened plants, animals and vegetation communities. Native vegetation is highly fragmented and covers about 30% of the region with approximately one quarter of this comprising lowland native grasslands and wetlands. Threats to the remnant native vegetation include land clearing and conversion to cropping, inappropriate fire and grazing regimes, and weed invasion.

Lowland native grasslands are the most depleted vegetation formation in Tasmania (Kirkpatrick et al., 1995) and are listed as critically endangered under the national *Environment Protection and Biodiversity Conservation Act 1999*. We distinguish between two categories of grassland community. First, there is the high conservation value Lowland Native Grasslands of Tasmania community (LNGT), which is made up of two floristic types; Lowland *Themeda triandra* grassland (GTL) and Lowland *Poa labillardierei* grassland (GPL) (Harris and Kitchener, 2005). Second, we consider a broader suite of vegetation that includes GTL and GPL along with two other mapping units that are similar in composition and geographic extent to LNGT; *Bursaria–Acacia* woodland and scrub (NBA) and Lowland grassland complex (GCL). The related units NBA and GCL are likely to be important in the long-term conservation of the LNGT.

2.2. Grassland distributions – future climatic envelopes

Harris et al. (2015) used Maxent (Phillips et al., 2006) to model the distribution of climate suitable for the listed and broad grassland community types under current and future climate conditions. Maxent is a Species Distribution Model (SDM), or climate envelope model, which uses presence only data to establish the statistical relationship between environmental or climatic variables and the current, observed distribution of a species or community. The future distribution of the community is then projected based on future climatic conditions.

Models of the distribution of climate suitable for grasslands were based on presence locations generated by randomly sampling 1000 points from within the existing distribution of each of the community types (GTL, GPL, GCL and NBA) from the state-wide vegetation map (DPIPWE, 2013). Given that it is unlikely that past distribution extended far beyond current range, sampling the current distribution is a reasonable approximation to the range of suitable climatic conditions.

The SDMs were based on the output of six dynamically downscaled climate models to capture the uncertainty due to the range in climate models. The results are presented here as the sum of the suitability projected by each of the six models (the bounding box), the total area where at least one climate models projected suitable climate to occur. This is likely to be a conservative estimate of the future extent of suitable climate, as individual models projected substantially smaller areas, in non-overlapping areas (see Harris et al., 2015). We focus on the mid-century time frame, because we seek to develop recommendations that can be implemented by policy makers by 2050 rather than beyond that time span.

The listed and broad grassland communities were mapped using a combination of the climate suitability modelling and current mapped extent of grassland communities in DPIPWE (2013). First, we identified current extent of grasslands within climatically suitable areas. We then identified areas of lowland native grassland projected to retain grassland-suitable climate in 2050. We also identified areas that are projected to be climatically suitable in 2050 that are also outside of their current geographic distribution. In total we produced six different grassland distribution maps: (2 combinations of extant grasslands [threatened and broad communities] × 2 time periods [current and 2050]) + (2 projected 2050 distributions of grassland-suitable climate outside of current extent). See supporting material for details.

To ensure that any difference between time periods is not a property of the change in source information, climate models of grassland extent were used rather than comparing TASVEG 3.0 mapping extent to modelled future extent. This was done to retain consistency between mapping methods and grid size for all GIS layers and therefore reduce the propagation of spatial uncertainty that can result from varying scale and classification methods (Lechner et al., 2012). We recognize that smaller patches of grassland will not be included due to the scale of the analysis. However, the focus of this analysis was on broad patterns of land manager adaptive capacity and grassland communities rather than property scale mapping.

2.3. Sample and survey instrument

Social data were collected using a mail survey of rural land managers in the Tasmanian Midlands. The survey population was comprised of land managers who owned properties larger than two hectares, to exclude urban residents. There were 250 surveys returned and answered comprehensively enough to use in analysis, comprising approximately 40% of surveys sent. The high survey response can be attributed to our use of a mail-based survey administered according to a modified Dillman (2007) Tailored Design Method. This method involved mailing an initial survey, two reminder post-cards at weekly intervals after the initial mailing, a second survey packet to non-respondents to the first round of mailing and finally a third reminder postcard one week after the mailing of the second survey. The survey questions relevant to this paper relate to adaptive capacity, self-reported participation in conservation programs and socio-demographic and property characteristics. The survey addressed seven dimensions of adaptive capacity (Table 1) that have since been tested and validated using confirmatory factor analyses techniques (Lockwood et al., 2015). The seven-dimension model of adaptive capacity had acceptable fit statistics: χ^2/df (chi-square/degrees of freedom) = 1.86, CFI (comparative fit index) = 0.913, and RMSEA (root mean square error of approximation) = 0.059. The mean responses to each of these dimensions emergent from the survey were used in the analyses. We then generated an overall capacity score by aggregating mean responses across the seven dimensions of capacity. These scores were translated into a heuristic of low, medium and high capacity based on the 33rd percentile. This aggregate score can be broadly interpreted as land manager's capacity to adaptively manage native vegetation on their property.

The survey included four scale items to represent self-reported participation in conservation programs (conservation incentives, conservation agreement, conservation covenant and Landcare). Participation was rated on a scale from “1 = participated” through to “4 = have not heard about the program”, translated post-hoc into a binary index of 1 = no participation in any of the four programs and 2 = some participation in any of the four programs. The survey also included a variety of socio-demographic variables related to age, gender, self-reported health, formal education, income, equity in the property, duration of family ownership of the property and whether respondent household's income was sufficient to meet life's necessities. Participants were also asked to report on the area (in hectares) of native grassland and native forests on their properties.

2.4. Integration of vegetation, climate and adaptive capacity data

We calculated the areas of listed and broad grassland communities within each respondent property, both extant and as projected to have suitable climate in 2050. The spatial unit for each respondent was derived from cadastral data where all the properties owned by each land manager were aggregated (see supporting information for more details). Survey respondents were then categorised into three levels of adaptive capacity (low, medium and high) and as commercial land managers (land managers earning the majority of their income on-farm) and lifestyle land managers (land managers earning the majority of their income off-farm). This enabled us to calculate the average percentage area of land owned by capacity category (high, medium, low) and by segment (commercial, lifestyle).

2.5. Associations between land manager characteristics and participation in conservation programs

It is important to consider land managers' willingness to engage in the conservation of lowland native grasslands to inform appropriate conservation strategies and future engagement by government or NGOs. For example, a landholder might have high adaptive capacity, but little interest in participating in conservation activities, posing specific challenges for future engagement. We examined the relationship between the seven dimensions of adaptive capacity and self-reported participation in conservation programs using Spearman Rho correlations. We also compared the associations among land managers' socio-demographic characteristics (age, gender, education, equity in property, profit), property characteristics (length of family ownership of property, property area, native grassland area, native forest area) and self-reported participation in conservation programs. These analyses allowed us to explore a range of potential influences on conservation participation, thereby adding to the suite of considerations that might assist conservation program design.

The correlation analyses identify the associations between conservation program participation and a variety of respondent variables. However, they do not examine how much of the variance in conservation program participation is explained by each variable. To this end, we used a standard binomial logistic regression (where multiple variables are incorporated simultaneously) to identify the extent to which socio-demographic, property characteristic and adaptive capacity variables could explain the variance in conservation program participation and non-participation. This analysis provides a separate line of evidence to validate whether adaptive capacity scores reflect conservation participation, or whether other socio-demographic or property characteristics are more closely associated with this dependent variable. Unlike explanatory modelling, this form of descriptive modelling is not aimed at prediction. Rather, such a regression model describes the association between the dependent and independent variables (Shmueli, 2010).

2.6. Utility of information sources

Conservation practitioners require guidance about the nature and type of investments that are likely to build community capacity

Table 1
The seven dimensions of adaptive capacity related to native vegetation management and empirically identified from survey responses.

Dimension of adaptive capacity	Description
Local networks	Extent of connections with local groups and their role in achieving grassland management goals.
Trust in government	Ability to trust local government information and to do what is right in terms of the management of grasslands.
Reciprocity	Land manager's sense of responsibility to make a contribution to the community they live in and the level of support offered by other community members.
Human, financial and physical capital	The human, financial or physical capital resources required to manage grasslands.
Innovation	Land manager openness to new ideas and willingness to try new things.
Adaptive management	Land manager ability to monitor and evaluate progress against management goals and ability to learn from their successes and failures.
Information behaviour	Land managers' use of information sources related to farm and land management.

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and promote the conservation of native grasslands. We therefore ranked the information sources perceived to be most and least useful to survey participants across capacity types and commercial and lifestyle land manager groups.

3. Results

The results are divided into four sections: (i) comparing lowland native grassland areas and future climate envelopes across different types of land managers and adaptive capacities; (ii) the associations between respondent property and socio-demographic characteristics, adaptive capacity and self-reported participation in conservation programs; (iii) identifying the elements that contribute to participation in conservation programs; and (iv) the relative utility of information sources as perceived by different types of land managers.

3.1. Grassland distributions across different time periods, land manager types and adaptive capacities

Table 2 describes the relationship between adaptive capacity and the current or projected future extent of listed and broad grassland communities (or grassland-suitable climate areas) within our study area. Approximately 40% of current-listed grasslands (sum = 2117 ha, mean = 78 ha/property) are projected to retain suitable climate by 2050. Broad grasslands are expected to fare better with approximately 88% of extent remaining climate suitable by mid-century (sum = 15,768 ha, mean = 166 ha/property).

Land managers with high self-reported adaptive capacity had larger mean areas containing listed and broad grassland communities in terms of current extent and projected 2050 climate envelopes than medium or low capacity land managers. For example, land managers with high adaptive capacity managed on average 94 ha of listed grassland expected to have suitable 2050 climate compared to 3 ha for low capacity land managers. However, the proportion of any property with grassland was similar and low (i.e. 1–7% for listed grasslands and 10–17% for broad grasslands), regardless of capacity type.

Commercial land managers owned larger areas of all grassland types (extant and future climate-suitable remnants) than lifestyle land managers. However, commercial land managers are also expected to face larger decreases in climate-suitable areas for native grassland than lifestyle land managers (commercial = 102 ha current to 88 ha in 2050; lifestyle = 5 ha current to 4 ha in 2050). Lifestyle land managers owned larger proportions of land that is not currently grassland but is projected to be climatically suitable for grassland in 2050. An average of 71% of land managed by lifestyle land managers will have listed-grassland suitable climate by 2050, compared to 42% of land managed by commercial land managers.

3.2. Associations between respondent property and socio-demographic characteristics, adaptive capacity and self-reported participation in conservation programs

Table 3 outlines the relationships between respondent characteristics, adaptive capacity and conservation program participation. Strong, positive and statistically significant ($p < 0.01$) correlations were found between property area and: (i) length of family ownership ($r = 0.515$); (ii) information behaviour ($r = 0.555$); (iii) native grassland or forest area ($r > 0.671$); and (iv) self-reported participation in conservation programs ($r = 0.561$). After property area, information behaviour had the next strongest ($p < 0.01$) correlation with conservation program participation,

Table 2
Mean area (ha) and percentage area of grasslands and number of managers with properties containing grasslands (managers with no grasslands on their property have been excluded).

Grassland community and time	Overall			Low capacity			Medium capacity			High capacity			Commercial land manager			Lifestyle land manager		
	Sum total area (ha)	Mean area (ha)	# Managers	Mean area (ha)	Mean % area	# Managers	Mean area (ha)	Mean % area	# Prop.	Mean area (ha)	Mean % area	# Managers	Mean area (ha)	Mean % area	# Prop.	Mean area (ha)	Mean % area	# Managers
Listed grasslands[a]																		
Current extent	5316	97	55	25	1	8	75	7	16	126	5	31	102	5	52	5	4	3
Current extent expected to have suitable 2050 climate	2117	78	27	3	4	3	73	7	7	94	3	17	88	4	24	4	7	3
Potential new areas [suitable 2050 climate envelope]	33,580	569	59	52	66	14	403	40	18	948	53	27	848	42	39	30	71	17
Broad grasslands[b]																		
Current extent	17,887	192	93	49	17	16	111	10	31	297	14	46	226	12	78	21	17	13
Current extent expected to have suitable 2050 climate	15,768	166	95	32	16	17	98	10	33	267	13	45	201	11	77	21	17	14
Potential new areas [suitable 2050 climate envelope]	98,566	563	175	104	74	51	430	64	56	1018	83	68	880	68	109	43	86	56

[a] Areas of either Lowland *Themeda triandra* grassland (GTL) or Lowland *Poa labillardierei* grassland (GPL) (TASVEG 3.0).
[b] Areas of either GTL or GPL or Lowland grassland complex (GCL) or Bursaria – Acacia woodland and scrub (NBA) (TASVEG 3.0).

Table 3
Bivariate correlations between variables hypothesised to influence past conservation program participation using Spearman's Rho.

	Profit/ necessities	Family ownership	Property area	HFP capital	Innovation	Adaptive management	Information behaviour	Native grassland (ha)[a]	Native forest (ha)[a]	Cons. program participation
Profit/necessities		0.129	0.184**	0.337**	0.189**	0.000	0.220**	0.103	0.094	0.137*
Family ownership			0.515**	−0.009	0.023	0.163*	0.432**	0.334**	0.340**	0.440**
Property area				−0.022	0.161**	0.152*	0.555**	0.671**	0.766**	0.561**
HFP capital					0.027	0.166**	0.011	0.004	−0.125	0.128*
Innovation						0.436**	0.378**	0.206**	0.056	0.176**
Adaptive management							0.307**	0.146*	0.012	0.165*
Information behaviour								0.445**	0.425**	0.516**
Native grassland (ha)[1]									0.471**	0.328**
Native forest (ha)[1]										0.398**

***$p < 0.001$; **$p < 0.01$, *$p < 0.05$.
[a] Native grassland (ha) and native forest (ha) are self-reported areas from the survey.

($r = 0.516$), followed by family ownership ($r = 0.440$) and native grassland or forest area ($r > 0.328$).

3.3. Elements contributing to participation in conservation programs

Overall the binomial regression model was statistically significant (Chi-square = 92.33, d.f. = 19, $p < 0.001$) and explained up to 65% of the variance in conservation program participation and non-participation (Nagelkerke R Square = 0.65). It also predicted an average of 83.3% of conservation program participation and non-participation cases. Similar proportions of each group were predicted.

Table 4 presents the logistic regression equation. Overall, we found that:

1) land managers whose family have owned the property for a longer period of time are 6.1 times more likely to have participated in conservation programs than land managers whose family have owned the property for a short period of time;
2) land managers with strong local networks are 8 times more likely to have participated in conservation programs than land managers with weak local networks; and
3) land managers with strong information seeking behaviour are 7.6 times more likely to have participated in conservation programs than land managers with weak information seeking behaviour.

Table 4
Variables in the binomial logistic regression equation (n = 138).

Variable	B	S.E.	Wald	df	Sig.	Exp(B)
Age	0.00	0.03	0.02	1	0.895	1.00
Gender	−0.67	0.76	0.76	1	0.384	0.51
Health	−0.02	0.25	0.00	1	0.944	0.98
Education	0.02	0.15	0.02	1	0.900	1.02
Profit	0.24	0.72	0.11	1	0.736	1.27
Equity	0.00	0.01	0.04	1	0.844	1.00
Profit/necessities	−0.73	0.37	3.82	1	0.051	0.48
Yrs prop owned by family	**0.02**	**0.01**	**6.10**	**1**	**0.013**	**1.02**
Property area	0.00	0.00	2.15	1	0.143	1.00
Business or lifestyle property	**−3.45**	**1.00**	**11.99**	**1**	**0.001**	**0.03**
Local networks	**1.38**	**0.49**	**8.03**	**1**	**0.005**	**3.98**
Trust in government	−0.40	0.38	1.14	1	0.287	0.67
Reciprocity	−0.02	0.55	0.00	1	0.965	0.98
HFP capital	0.49	0.35	1.95	1	0.163	1.64
Innovation	0.24	0.56	0.19	1	0.664	1.27
Adaptive management	−0.58	0.50	1.36	1	0.244	0.56
Information behaviour	**1.17**	**0.42**	**7.68**	**1**	**0.006**	**3.23**
Native grassland ha	0.00	0.00	0.73	1	0.393	1.00
Native forest ha	0.00	0.00	2.76	1	0.097	1.00
Constant	−1.17	3.57	0.11	1	0.743	0.31

Dependent variable: Non-participation (1) or past participation (2) in any one of the following conservation programs: Conservation Incentives, Conservation Agreement, Conservation Covenant, Landcare.
Bold lines denote significant predictors.
All independent variables were entered on Step 1.
The Beta co-efficient represents the direction of the association, the Exp(B) represents the relative strength of the association and the Wald test represents the extent to which the model predicts conservation program participation over non-participation.

These findings support the results of the correlation analyses in that information behaviour, local networks and years of family property ownership are associated with conservation program participation. However, unlike the correlation findings, profit and property area variables are not associated with conservation participation when holding the dependent variable constant. Further, local networks becomes an important predictor of conservation program participation, even though only a weak correlation was found between these variables in the preliminary correlation analyses ($r = 0.257$).

3.4. Importance of different information sources for land managers

Given the strong positive associations between information behaviour and conservation program participation, we ranked the different types of information sources in terms of their perceived usefulness to respondents (Table 5). Other land managers, the rural press and internet were consistently identified as the most useful information sources across all capacity and land manager types. Radio and the local Tasmanian Midlands newspaper (a newspaper available to the general public) were ranked in the top five most useful sources by lifestyle land managers and private agronomist/consultants were ranked in the top five by commercial and high capacity land managers.

Social media, conservation NGO staff and specialist training programs were consistently identified as the least useful sources of information across all land manager types. In contrast, the local Tasmanian Midlands newspaper was ranked in the top five least useful sources by commercial and high capacity land managers, but as noted above in the top five most useful sources by lifestyle land managers.

4. Discussion

We focus our discussion on how community engagement programs may need to be configured as a result of considering aspects

Table 5
Mean rank comparison of the usefulness of information sources by overall adaptive capacity strength and land manager type.

	Overall mean	Mean rank	Low capacity	Medium capacity	High capacity	Commercial	Lifestyle
Other land managers/land managers	2.75	1	✓	✓	✓	✓	✓
Rural press (e.g. The Land, Weekly Times)	2.60	2	✓	✓	✓	✓	✓
Internet	2.55	3	✓	✓	✓	✓	✓
Farm industry newsletters or brochures	2.48	4		✓	✓	✓	
Radio	2.41	5	✓	✓			✓
Landcare, NRM or DPIPWE newsletters/brochures	2.25	6					
TV	2.25	7	✓		×		
Private agronomist/consultant	2.19	8	×		✓	✓	×
Field days	2.19	9					
Local midlands newspaper	2.16	10			×	×	✓
Landcare, NRM or DPIPWE advisory staff	1.96	11		×	×		
Farm industry advisory staff	1.91	12	×	×			×
Specialist training programs	1.79	13	×	×	×	×	×
Conservation NGO staff	1.46	14	×	×	×	×	×
Social media (e.g. Facebook, Twitter)	1.32	15	×	×	×	×	×

✓ = within the 5 most useful sources of information; × = within the 5 least useful sources of information. Mean scores 1 = Never used through to 4 = Very useful.

of grassland conservation priority alongside aspects of management feasibility. We then provide examples of community engagement strategies tailored to the capacity type and strengths of individual land managers.

4.1. Incorporating changing grassland distributions and adaptive capacity into community engagement programs

In the introduction to this paper, we asserted that aspects of grassland conservation priority need to be considered alongside aspects of management feasibility (including adaptive capacity) if grassland communities are to be effectively conserved by individual private land managers. Grassland priorities also need to be informed by current extents and projected future distributions of these communities under a changing climate.

Actions that focus exclusively on current distributions may assist conservation of large extents of healthy, predominantly native, listed grassland communities across all landholder types. However, when managing for current distributions, our results suggest that the best conservation outcomes can be achieved by engaging with land managers with high capacity, including strong social networks and good information behaviour. These land managers tend to be commercially-oriented land managers who own large extents of grasslands, often in good condition.

However, retaining ecological processes and structural habitat for many faunal species under climate change requires a different approach to environmental management (Starzomski, 2013). Plausible climate change scenarios indicate that grassland-suitable climate will disappear across half of the current extent of listed grasslands. We therefore need to change the dominant conservation paradigm of conserving listed communities only, to one that recognises the contribution of broad grasslands and novel ecosystems in meeting high-level conservation goals. Climate change is predicted to result in irreversible changes in abiotic and biotic conditions leading to the development of degraded or novel ecosystems for which there are no current analogues (Williams and Jackson, 2007; Starzomski, 2013). Thus, remediation and management efforts to return vegetation to a prior state, or even to maintain existing state, may often be unrealistic (Zedler et al., 2012). While commercial land managers remain important to engage in grassland management, lifestyle land managers are also likely to play an important role in managing broad grasslands and novel ecosystems in future climate change scenarios, where they support native species and processes. Despite small areas, lifestyle land managers own a higher proportion of land by property area (86%) that is climatically suitable for grasslands than commercial land managers (68%).

These changing proportions of grassland by land manager type have implications for the engagement of land managers similarly facing climate-induced ecological changes in other vegetation types and regions. According to the survey results, participation of land managers in grassland conservation programs can be enhanced by improving access to good quality information about native grassland values and management through neighbouring land managers and creative use of the local press, internet and other new technologies. This is particularly the case for land managers with high adaptive capacity and information seeking behaviour. Focussing on methods of grassland management that align closely with many existing farming systems, such as low stocking rates and non-continuous grazing techniques, may achieve greater acceptance amongst commercial land managers than more challenging approaches to manage native grasses when faced with climate change, such as the use of fire or changing the time of grassland harvest for hay or silage to enable seeding.

In contrast, lifestyle owners are less likely to participate in traditional forms of conservation programs such as covenanting, but may be receptive to programs that link conservation values to amenity values, particularly recreation. Linking the benefits of grassland conservation to values derived from adventure recreation pursuits (e.g., horse riding, mountain biking, motorcycle riding) and more passive forms of recreation (e.g., bird watching, bushwalking) are more likely to engage this group. Conservation agencies may therefore consider developing field days that combine an education and awareness raising component about native grasslands with a leisure component. The type of leisure activity will be influenced by the recreation preferences of particular types of lifestyle farmers, and could be informed by further recreation preference surveys.

The discussion to date has focussed on designing engagement approaches informed by an understanding of the relative adaptive capacity of land managers. Equally important are the relationships between adaptive capacity and information behaviour. Individual adaptation depends upon whether an impact is perceived as a risk and whether it should be acted upon. Risk perception is in-turn influenced by a range of fundamental processes including cognitive beliefs which are often shaped by the type of knowledge and information one accesses (Adger et al., 2009). The next section addresses the question of how to tailor community engagement programs according to the adaptive capacity and information behaviour of land managers.

4.2. Tailoring community engagement programs according to adaptive capacity and information behaviour of land managers

The finding that conservation program participation is more prevalent among commercial land managers with strong local networks, strong information behaviour and whose family have lived in the region for a long period of time, highlights the important role of directing efforts to building connections among local networks of farmers, and to exchanging knowledge and information through local networks. This view is supported by recent research which highlights the importance of working with local trusted advisors, including farm system groups and farm consultants, to diffuse knowledge and information on human-induced climate change (Raymond and Robinson, 2013), among other farm-based conservation issues (Dinnie et al., 2015).

The importance of local networks is reinforced by the finding that Landcare, natural resource management and state government advisory staff were reported as less useful as a natural resource management information source than private agronomists or consultants, particularly amongst high capacity land managers. These findings may reflect issues of land manager trust in government affiliated organisations. Issues of trust have been found to influence public approval of natural resource management decisions (Vaske et al., 2007; Lachapelle and McCool, 2012) and to be an important driver of collaboration or conflict in natural resource management projects (Ostrom, 2003; Fulmer and Gelfand, 2012). We don't believe that these results undermine the need for government advisory staff support. Rather, we encourage a reflection on their role within the knowledge and information dissemination process. Instead of being direct providers of knowledge and information, they could empower local farm system groups and known farming champions to diffuse grassland management and climate change knowledge and information on their behalf. Hence, their role changes from knowledge provider to knowledge broker.

The existing strong networks and relationships within high adaptive-capacity land managers could be supported through social activities such as barbecues, quiz nights and other outlets for socialising that are linked to farm field days or business planning events. Environmental agencies could work in partnership with farm system groups and conservation NGOs to develop climate change and grassland management information sessions which occur at these events. In contrast, conservation efforts by land managers with low adaptive capacity could be improved through formalized programs to link with conservation NGOs and government-supported conservation groups. Such programs may result in 'meet and greet' occasions with respected leaders from these groups, to discuss grassland management issues and concerns. For example, environmental agencies and conservation NGOs could partner with leisure and sporting clubs (e.g., horse-riding clubs, community supported agriculture groups) composed of large members of hobby and lifestyle farmers to build networks and diffuse information. In many instances, land managers owning smaller areas of land are likely to be interested in these types of programs given the strong positive correlations found between adaptive capacity strength and land area.

The strategy of spatially analysing social data (in particular adaptive capacity), future climate suitability and distributions of key biodiversity assets is a powerful way to assess future prospects for biodiversity conservation in privately owned agricultural landscapes in other areas, considering it:

1) moves beyond only assessing ecological value and threat (elements of conservation priority) to an assessment of the feasibility of implementing adaptation strategies;
2) recognises the important role that end-users (in this case land managers) have on the conservation and restoration of native grassland communities, not just conservation societies and formal institutions such as government agencies; and
3) highlights that the nature of community engagement will vary depending upon the interplay between capacity type and strength, as self-reported by land managers, whereas previous approaches have principally focussed on these elements in isolation (e.g., Knight et al., 2010).

By adopting our approach, government agencies and NGO seeking to improve conservation outcomes would be better equipped to work with each subgroup of private land managers using specifically-targeted communication channels and messages that take into account variations in capacity to manage change.

4.3. Future directions

There is a potential disconnect between the 2050 grassland distribution scenarios and adaptive capacity. Self-reported adaptive capacity was measured based on present conditions whereas grassland distributions were projected to 2050 based on climate data. It is unclear how the structure and content of local networks and information behaviour will change based on 2050 scenarios. Uncertainty in future adaptive capacity is related to: i) change of property ownership; ii) change of markets driving different agricultural practices; iii) other environmental changes associated with climate change such as bushfire; and iv) potential changes to environmental policy. Changes to property ownership may affect future adaptive capacity given our finding that those farmers who have lived in the Tasmanian Midlands for a long period of time have higher adaptive capacity than those who have entered the region more recently. Market changes (e.g., the rise of dairy production in the Midlands) in turn creates land-use changes (e.g., shifts from dryland to irrigated agriculture). Our findings indicate that those landholders who have already made shifts to irrigated agriculture tend to have high overall adaptive capacity; however, further market variations are likely to change the types of capacities needed to successfully manage properties in the Midlands.

It is also unclear how environmental adjustments associated with climate change will influence adaptive capacity. Australia has a strong culture of volunteering to help rural land managers during times of crises (e.g., bushfire). It is possible that adaptive capacity, particularly the strength of networks and relationships, will increase as the intensity of frequency of such crises increase. Environmental policies, including those aimed at improving knowledge and awareness of grassland management options, may have a bearing on adaptive capacity as noted in the previous section. Future studies may include modelling adaptive capacity based on demographic and property sale trends to better understand the potential for change in future adaptive capacity. In the meantime, it would be prudent for environmental agencies and conservation NGOs to tailor their programs based on current levels of adaptive capacity, as measured here, given many of these future considerations which affect adaptive capacity are difficult to forecast. We recommend future studies to test the causality of the identified relationships using quasi-experimental designs. This could be achieved by comparing the responses of participants in grassland conservation programs to non-participants. The self-reports of capacity and program participation could also be validated by comparisons with independently observed capacity and participation levels. Additionally, more useful proxies of grassland management may exist than self-reported conservation program participation. Such participation proxies could be validated by comparing the conservation and restoration efforts of program participants to a wider sample of non-participants.

This study also did not assess the influence of climate change awareness on a range of adaptive capacities. Quasi-experimental designs involving strict controls on current knowledge levels and adaptive capacity types could be employed in future research to understand such relationships.

5. Conclusions

Commercial land managers are experienced at dealing with seasonal and inter-annual variability in climate conditions, but the long-term changes projected to occur under climate change are likely to pose new challenges. In the Tasmanian Midlands, suitable climate for native, listed grasslands is projected to disappear across half of their geographic extent. Also, areas outside of the current extent of lowland native grasslands are projected to develop grassland-suitable climate by 2050. These areas may be of new conservation priority, and restoring grassland on degraded land may present a conservation opportunity. Extant grasslands in areas projected to have unsuitable climate by 2050 may degrade or transform into novel ecosystems as a result of irreversible changes in abiotic and biotic conditions due to climate change, and this poses a large conservation challenge to land managers.

Based on our assessment of existing adaptive capacity, all land manager groups have an important role to play in the management of lowland native grasslands as they persist, decline or transform into the future. High capacity land managers have the largest current extents and projected envelopes of listed and broad grasslands (by mean area). While smaller areas, a high proportion of land (>64%) managed by low and moderate capacity land managers is likely to be suitable for broad grasslands based on 2050 projections. We present a land manager engagement approach that enables environmental management organisations to target their efforts and tailor their messages to land managers with different capacity types and strengths. This approach broadly involves sharing grassland knowledge and information relevant to manager needs, including distributions of grassland types across the Midlands, how these distributions are expected to change, and the potential benefits of implementing actions such as ecologically-informed fire regimes. Our data suggest that such knowledge and information is best communicated through coordinated events that enable low capacity land managers to network with, and learn from, knowledge brokers and respected members of their local community. Commercially-oriented land managers who own large extents of grasslands tend to have strong social networks and actively seek information to support improved management. Strategies to engage these managers can take advantage of these strengths through measures that are congruent with existing farming systems and developing knowledge through private consultants and partnerships with scientists. In contrast, the management capacities of lifestyle owners can be supported through engagement programs that use rural press outlets to link changing conservation values to amenity values. The approach of integrating data on vegetation distribution, climate change, and land managers' adaptive capacities and propensities to engage in conservation action, has application to the design of engagement strategies elsewhere.

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