Mapping Scenario Narratives: A Technique to Enhance Landscape-scale Biodiversity Planning

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Abstract

Developing regional scenarios enables planners to engage land managers in discussions about the future, especially in contexts that are complex, uncertain and difficult to control. Richly-crafted qualitative narratives are an effective way to document future scenarios that integrate social, economic and biophysical attributes. Converting such narratives into spatial representations of future landscapes often relies on computational modelling. This paper presents an alternative technique. Key themes from scenario narratives are translated into spatial representations using simple rule sets within a Geographic Information System (GIS). The technique was applied to a case study exploring future scenarios for biodiversity in a predominantly privately-owned agricultural landscape. Iterative analysis of scenarios and their spatial implications enables land managers to explore outcomes from potential interventions and identify strategies that might mitigate the impact of future issues of environmental concern.

Keywords: spatial planning; alternative futures; scenario visualisation; landscape change; private land conservation; Tasmanian Midlands

INTRODUCTION

The current global decline in biodiversity is largely attributed to human-induced impacts (Millennium Ecosystem Assessment 2005; Butchart et al. 2010). The associated genetic and functional losses are placing the integrity of our planetary biosphere at risk (Steffen et al. 2015). Chief among the human-induced drivers of change has been intense use of the most naturally productive landscapes to provide food and fibre for increasingly affluent, urbanised and growing populations (Haines-Young 2009). As a result, biodiversity conservation strategies need to be integrated with regional planning, and this requires a shift from focusing on assets and species alone towards increased appreciation of landscape-scale conditions and approaches (Bennett et al. 2009; Curtis and Lefroy 2010; Benson 2012). Conservation strategies also need to recognise that attempting to preserve pristine biodiversity "as is" will no

longer be feasible under climate change (Dunlop et al. 2013; Mitchell et al. 2016a).

Anticipating landscape-scale futures for biodiversity given climate change projections requires expert input, an appreciation for complex systems analysis, and a preparedness to consider the 'possible' not just the 'probable' (Hanspach et al. 2014; Rickards et al. 2014; Mitchell et al. 2016b). Improvements in modelling climate change trajectories have enabled a greater level of detail about future climate conditions for particular regions, but there remains a high level of uncertainty in anticipating the impacts of these changes given the influence of other social, economic and biophysical variables. Generating contrasting future scenarios based on systems analysis has therefore become a widely-used planning tool in such contexts of high uncertainty, especially where variables affecting futures are difficult to control (Peterson et al. 2003; Xiang and Clarke 2003). Representing such contrasting scenarios in visual form greatly aids stakeholder engagement in planning (Sheppard et al. 2011) by allowing exploration and prioritisation of alternatives (Pert et al. 2013), increasing understanding of landscape issues and processes (Salter et al. 2009; Valencia-Sandoval et al. 2010), and providing a common basis for communication (Tobias et al. 2016).

This paper presents a technique for spatially representing scenarios that have been articulated using rich textual information. The technique is intended to be simple, transparent and easy to implement. It involves applying rule sets derived from scenario narratives to pre-existing spatial data to generate maps of the major land use implications of each scenario. The paper focuses on the novel aspects of the technique and potential for further development, including explanations of how outcomes could be used by land managers to enhance biodiversity planning.

SCENARIOS AND REGIONAL PLANNING

Scenarios have been used for a range of regional planning purposes. Those incorporating spatial analyses have been undertaken to imagine future possibilities not otherwise anticipated (Palomo et al. 2011), to raise awareness about plausible landscape futures under climate change (Jung and Chang 2012) – including if status quo planning arrangements are maintained (Pert et al. 2010), to explore different policy options (Dockerty et al. 2006), and to prompt discussion about governance arrangements that are likely to support preferred regional futures (Southern et al. 2011). Most of these efforts involve processes to actively engage stakeholders in generating the scenarios and discussing their implications. Scenarios are often identified using the four spaces defined by the extreme expressions of two critical uncertainties (Rickards et al. 2014). In some cases, these critical uncertainties are given, as in the UK Climate Impacts Programme (Berkhout et al. 2002), while in others these are determined by stakeholders through workshop activities (e.g. O'Connor et al. 2005).

Visualisation techniques can help to convey implications of scenarios, thereby providing a useful vehicle for engaging

stakeholders in discussions about alternative futures (Sheppard et al. 2011). Such techniques include photo montages (Van Berkel et al. 2011), films (Reed et al. 2013), impressionistic maps (Milestad et al. 2014), virtual reality (An and Powe 2015; Lovett et al. 2015), and spatial representations of future land use and/or land cover changes (Santelmann et al. 2004). The level of complexity involved in anticipating scenarios related to biodiversity futures means that their spatial representations are most often developed using computational integrated modelling procedures (Rounsevell et al. 2006; Nelson et al. 2009; Turpin et al. 2009; Norman et al. 2012; Price et al. 2016). Such approaches tend to be computationally expensive, highly parameterised, opaque, and time-consuming. These characteristics limit the potential for quantitative modelling approaches to support effective stakeholder engagement, as there is little capacity for flexible iteration between developing scenarios and discussing their spatial implications. Simpler and more flexible strategies to engage stakeholders in identifying and interpreting implications of future land use scenarios are therefore needed.

Another strategy for engaging stakeholders in scenario development is to draw on their input in the construction of descriptive storylines or narratives (Kok et al. 2011; Foran et al. 2013). Scenario narratives can overcome the shortcomings of visual techniques related to perception bias (Soliva and Hunziker 2009), and enable more detailed comparison of scenarios brought about by the differential effects of key drivers (Plieninger et al. 2013; Reed et al. 2013; Mitchell et al. 2016a). However, processes that ensure participants have control over the production of narrative texts can be time-consuming, and in many cases, involve a pre-determined basis upon which the four-space range of scenarios are identified (Mitchell et al. 2016a). While participatory approaches enhance saliency and legitimacy, credibility may be undermined by insufficient diversity of those involved, and the challenges participants may have in developing a thorough understanding of the system being analysed (Rounsevell and Metzger 2010).

Combining the benefits of scenario narratives with visualisation is challenging. The qualitative nature of scenario narratives makes it difficult to convert them into maps that are sufficiently detailed to enable discussion about future land use planning. Lamarque et al. (2013) used 'what if' role playing workshop activities to convert expert-derived rich storylines about possible futures into mapped land use consequences. The process required substantial cross-checking to convert the role-playing game results into quantitative data that could be represented spatially. Reed et al. (2013) used computational modelling to map specific aspects of scenario narratives related to policy decisions, such as modelled carbon emission levels under different scenarios. Kok and van Delden (2009) used a bespoke software programme to convert stakeholder-developed narratives into quantitative data for map generation, but noted that their approach 'is very resource demanding and success is not guaranteed' (Kok and van Delden 2009: 62). Simpler processes that rely on rule sets to modify current land use patterns for future scenarios have been developed by

Waldhardt et al. (2010) and Bragagnolo and Geneletti (2013), but these did not involve the use of narratives. Our approach applies the use of simple rule sets to scenarios that had been developed as rich text narratives.

METHODS

The case study area was the Tasmanian Northern Midlands Bioregion in Australia (Department of the Environment 2013), a highly modified and predominantly privately-owned agricultural landscape, 415,445 ha in extent (see Figure 1).

The broader research project involved the use of scenario planning with stakeholders to explore landscape-scale biodiversity management and governance improvements (see www.lifeatlarge.edu.au/ and Mitchell et al. 2016b).

Four scenarios for the year 2030 were identified through activities at a one-day workshop in 2013 involving 27 participants including government and non-government agency staff, rural landholders and scientists. These participants were purposively selected for their local expertise. Many were actively involved in efforts to improve land management practices and biodiversity outcomes in the region (Mitchell et al. 2016a). The workshop process used to develop the scenarios was preceded by a wide-ranging social-ecological systems analysis of biodiversity in the region. This analysis involved consultation and validation with key stakeholders (Mitchell et al. 2015).

A four-space matrix was used to identify scenarios at the extreme positions of two critical uncertainties, with the worst-case scenario in top left position and best case scenario in bottom right position (see Figure 2). Participants chose two critical uncertainties by scoring key drivers of change identified from the prior systems-based analysis in terms of—1) their importance and then 2) their levels of uncertainty. The two critical uncertainties identified were farmer profitability, and human and social capital. That is, of the drivers of change identified as most important by participants, these two were subsequently identified as having the highest levels of uncertainty regarding their future states (see Mitchell et al. 2016a for further details). Farmer profitability reflects the uncertainty of future prospects for agriculture in the region given global competition and other market forces that affect landholder terms of trade. Uncertainty regarding future levels of human and social capital in the region is a consequence of difficulty in predicting outcomes from complex interactions between agricultural intensification, corporatisation of farm governance, rural depopulation and emerging landholder networks.

Narratives (summarised in Figure 2) were created for each scenario based on notes developed at the workshop. These narratives were further developed to flesh out details for each future scenario according to all the key drivers of change by drawing on supplementary information and suggestions acquired through two rounds of subsequent interviews with relevant scientific and local experts (see Mitchell et al. 2016a for further details). A strength of these narratives was their structure which resulted in detailed storylines for all the key drivers of change that had been identified through the prior systems analysis. The 8,000 word narratives then formed the basis for a separate map generating process.

The process used to develop maps from the scenario narratives is summarised in Figure 3. The spatial distributions of current land uses were compared with the descriptions offered for future plausible land uses under each scenario. To create maps of projected future land use that matched each scenario narrative, aspects of the descriptions were translated into spatial rules using existing GIS data, as explained below. A range of future steps that could be undertaken are also shown in red.

Current and projected future land uses were classified into five types–1) Irrigated Agriculture; 2) Non-irrigated Agriculture; 3) Other Rural Enterprises (including land with potential for native vegetation rehabilitation); 4) Conservation; and 5) Services and Utilities. These broad land use types provided a level of differentiation appropriate to representing scenario narratives in a way that facilitated consideration of policy implications. The land use category 'Other Rural Enterprises' refers to areas that may be used for non-agricultural purposes such as conservation, hunting, tourism and recreation, especially in scenarios under low farmer profitability.

The Tasmanian State Government's Land Use spatial layer developed by the Department of Primary Industries, Parks, Water and Environment (DPIPWE 2010) was used to represent
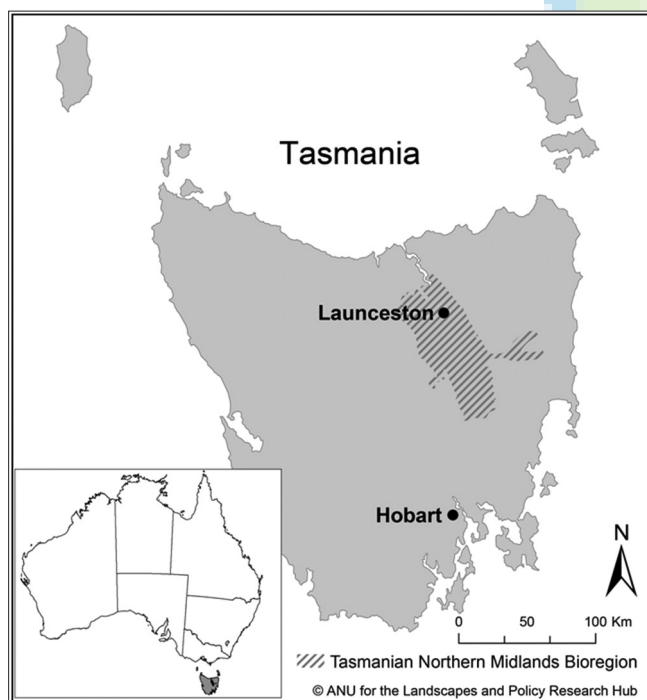

Figure 1
Tasmanian Northern Midlands Bioregion based on the Interim Biogeographic Regionalisation for Australia developed by the Australian Government (Department of the Environment 2013)

Figure 2
Summary of scenario narratives developed for the year 2030 in the Tasmanian Midlands (Source: Modified from Mitchell et al. 2016b)

|		Farmer Profitability	
		Low	High
Social and Human Capital	**Low**	**Death by a Thousand Cuts**	**Cha Ching**
		Slow demise of agricultural enterprises leads to increase in land no longer used for agriculture	Corporate agribusinesses dominate undermining social cohesion and community sense of place
		Little capacity among rural landholders to adjust to change	Irrigation used extensively with little regard for long-term impacts
	High	**People's Republic of Northern Midlands**	**Marvellous Midlands**
		High multi-property collaboration among farmers to improve water retention in the landscape	Landscape prized for potential to combine pursuit of lifestyle, profits and rural heritage values
		Strong sense of place drives development of alternative rural economic and lifestyle enterprises	Vibrant community drives development of innovative pro-sustainability agricultural enterprises
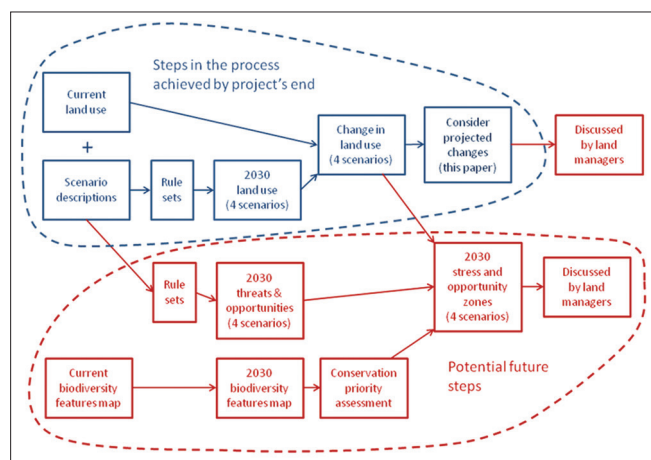
Figure 3
The process used to generate broad land use maps for four 2030 scenarios developed for the Tasmanian Midlands, Australia

'current' land use, with amendments based on additional pivot irrigation areas identified by DPIPWE in 2013. From this output, 73 specific land use types were aggregated into the five broad types listed above.

For each of the four scenario narratives (as summarised in Figure 2), passages of text were identified that indicated expected land use in particular parts of the region by 2030. These indications of land use type and location were translated into spatial rules suitable for application in a GIS platform, and the rules were then applied to modify the 'current' land use layer (see examples in Table 1).

The rules that were derived for the mapping process were informed by the GIS datasets available, and bounded by the scope of the scenario narratives. For each scenario, between seven and nine spatial rules were applied. Where there was conflict, such that one rule suggested one land use type but another rule suggested a different land use type, rules were ranked in order of the most likely future land use as anticipated by the research team. Draft maps were then developed using the spatial rules, and an iterative process applied to manipulate rules to better represent key characterisations of each scenario. The final rule sets used for each scenario are listed in Table 2.

RESULTS

We present the results as a set of maps at a coarse spatial scale (around 500m grid cells), depicting current land use (as of 2009–2010) and the four 2030 scenarios (see Figures 4 and 5), and as a table showing 1) total and proportional areas under each of the five land use types and 2) changes from current land use (see Table 3).

The colour scheme used in Figure 4 and 5 was selected to assist visual identification of the most pronounced changes in land use. These can then be verified by the data provided in Table 3. The most pronounced changes are:

1. A shift from 'Non-irrigated Agriculture' to 'Other Rural Enterprises' in the two low farmer profitability scenarios, 'Death by a Thousand Cuts' (Figure 5a) and 'People's Republic of Northern Midlands' (Figure 5c) The extent of land conversion demonstrates the impact that would occur if, by 2030, there was a substantial shift away from agriculture as a profitable source of income for rural landholders

2. An increase in area devoted to 'Irrigated Agriculture' across all scenarios, and particularly for the two high farmer profitability scenarios, 'Cha Ching' (Figure 5b) and 'Marvellous Midlands' (Figure 5d): This result indicates 2030 futures given current and ongoing expansion of irrigation development in the region, but also visually demonstrates the extent of that change under scenarios where rural landholders are able to benefit from profitable agricultural returns. The extent of irrigation expansion is larger under the 'Marvellous Midlands' scenario compared with 'Cha Ching'. Given that a key characteristic of the 'Cha Ching' scenario was that areas under irrigation would be maximised, this unexpected result of comparatively larger irrigated area for 'Marvellous Midlands' attests to the positive impact of that scenario's higher levels of social capital on the ability of rural landholders to enhance the extent and use of irrigation through collaboration. These impacts were described in the narratives, but the visual display clarified where in the landscape that collaboration would have most impact

3. An increase in area reserved as 'Conservation' in the

Table 1
Examples of scenario narratives and corresponding spatial rules

Example Scenario Text	Inference to land use change	Spatial rule applied
In Death by a Thousand Cuts scenario: "*Farmers with access to the Macquarie and South Esk Rivers have started to benefit from increased river flows (anticipated in regional climate change models) and divert water to farm dams, while other farmers endure flooding and/or waterlogged soils.*"	Infers that areas near the Macquarie and South Esk Rivers will convert to irrigated agriculture, where possible	1. Apply a 2 km buffer to Macquarie and South Esk Rivers layer (using hydrographic line data from DPIPWE [2009]) and save as a new mapped unit (polygon) 2. Attribute the new map unit in 1. as "Irrigated Agriculture"
In Cha Ching scenario: "*Some time-strapped farmers are willing to abandon use of portions of their less productive land. Landholders reserve some of their "back country" for conservation, as they can make more money by doing this than from any other activity . However, on balance grassland conservation is a very small part of the land use mix, and grasslands no longer exist on productive land and have become extremely rare.*"	Infers that land used for conservation purposes is generally restricted to less productive "back country"	1. Select "back country," defined as mapped "steep mid-slopes and crests, ridges and upper slopes" (based on landform categories derived from Gallant and Dowling [2003]) 2. Within back country areas, select locations where there is high conservation value (as determined by a conservation prioritisation score developed by the lead author - see notes below Table 2), and attribute these as the "Conservation" land use type

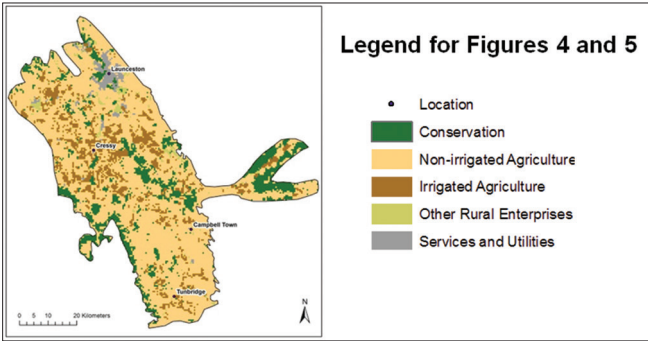Sources: DPIPWE 2009, Gallant and Dowling 2003

Figure 4
Land use as at 2009/10

Figure 5
Projected land use by 2030 under four scenarios (a) Death by a Thousand Cuts, (b) Cha Ching, (c) People's Republic of Northern Midlands, and (d) Marvellous Midlands

'Marvellous Midlands' scenario (Figure 5d): It is important to note that the actual increase in area where conservation strategies could be implemented may be larger than the areas shown in the dark green colour indicating 'Conservation'. Indeed, the lighter yellow-green colour used for 'Other Rural Enterprises' is intended to indicate their potential for conservation activities to be incorporated as part of the land use of these areas, as described in the scenario narratives. This includes descriptions in the 'Death by a Thousand Cuts' scenario narrative of land no longer used for agriculture being purchased for conservation purposes, and descriptions of former ephemeral wetland areas in the 'Marvellous Midlands' scenario being rehabilitated to serve dual purposes of water retention and biodiversity conservation.

DISCUSSION AND CONCLUSION

The spatial representations of future scenarios demonstrated in this paper have been designed to facilitate discussion among land and biodiversity managers concerning long-term planning strategies. In particular, the maps help identify new areas likely to become available for conservation. Discussion based on these 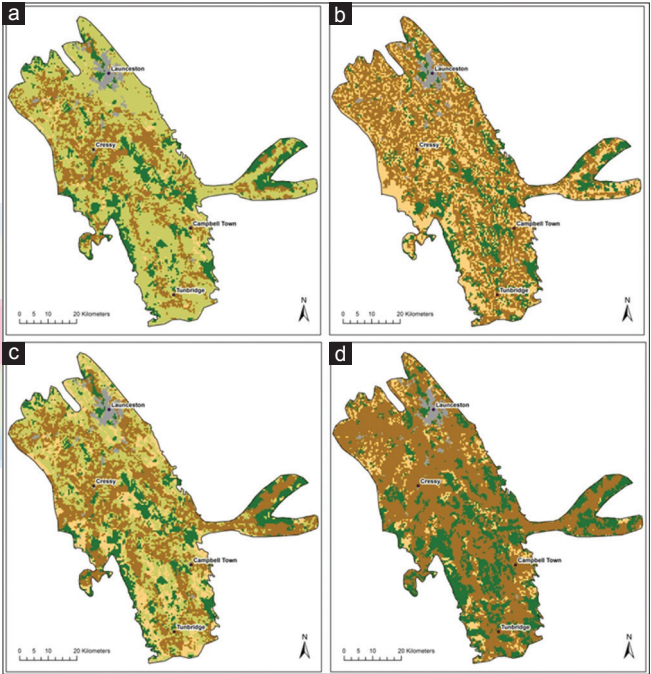maps can inform land management strategies related to land clearing, and possibilities for combining land use for profit with land that supports conservation. Because the maps are based on an extreme range of plausible scenarios that stretch the imagination from what is conventionally considered as 'probable' to what might actually be 'possible' (Rickards et al. 2014), discussions that form the basis for future regional-scale conservation planning are also opened up to new possibilities.

For example, the plausible increase in irrigation extent by 2030, especially in the 'Cha Ching' (Figure 5b) and 'Marvellous Midlands' scenarios (Figure 5d), could influence the location of areas managed or legally protected for conservation. These areas could include those that hold minimal prospects for

Table 2
Summary of rules for mapping land use under four 2030 scenarios for the Tasmanian Midlands (within each scenario, each rule takes precedence over subsequent rules)

Scenario (in bold) and spatial extent rule	Likely 2030 land use
Death by a Thousand Cuts	
1. Areas mapped as "Services and Utilities" in DPIPWE (2010) Land Use layer	As given in 2010 Land Use layer
2. Areas within the Tasmanian Reserve Estate (DPIPWE 2014)	Conservation
3. Areas with moderate to severe gully erosion from DPIPWE data (Grice 1992)	Other Rural Enterprises
4. 4.Landforms that are ridgetops, upper slopes, mid slopes, lower slopes or rises in lowland alluvial fill or long gentle sloping footslopes that are mapped as "non-irrigated agriculture," based on DPIPWE (2010)	Other Rural Enterprises
5. Areas of high conservation value (based on an unpublished conservation prioritisation score developed for DPIPWE by the lead author**)	Conservation
6. Areas within 2 km of major tributaries*	Irrigated Agriculture
7. Other areas not affected by above rules	As per the Tasmanian Land Use layer DPIPWE (2010) and pivot irrigation mapping undertaken in 2013
Cha Ching	
1. Areas mapped as "Services and Utilities" in DPIPWE (2010) Land Use layer	As given in 2010 Land Use layer
2. Areas within the Tasmanian Reserve Estate (DPIPWE 2014)	Conservation
3. Landforms that are ridge tops, upper slopes or rises in lowland alluvial fill or long gentle sloping footslopes	Non-irrigated Agriculture
4. Areas that are "back country," i.e., ridgetops, upper slopes, mid slopes and lower slopes (based on Gallant and Dowling [2003]) that are >1 km from a major road	Conservation
5. Areas within 2 km of major tributaries*	Irrigated Agriculture
6. Landforms mapped as mid slopes, lower slopes, valley fill in upland landscapes and large expanses or in-filled valleys and alluvial depositions	Irrigated Agriculture
7. Other areas not affected by above rules	As per the Tasmanian Land Use layer DPIPWE (2010) and pivot irrigation mapping undertaken in 2013
People's Republic of Northern Midlands	
1. Areas mapped as "Services and Utilities" in DPIPWE (2010) Land Use layer	As given in 2010 Land Use layer
2. Areas within 50m of major tributaries*	Other Rural Enterprises (as potential rehabilitation)
3. Areas within the Tasmanian Reserve Estate (DPIPWE 2014)	Conservation
4. Areas mapped as Lowland *Themeda triandra* grassland or Lowland *Poa labillardierei* grassland using TASVEG 3.0 (Kitchener and Harris 2013)	Conservation
5. Landforms that are ridgetops, upper slopes or mid-slopes and which are mapped as Non-irrigated Agriculture, based on DPIPWE (2010)	Other Rural Enterprises
6. Areas within 2 km of major tributaries*	Irrigated Agriculture
7. Other areas not affected by above rules	As per the Tasmanian Land Use layer DPIPWE (2010) and pivot irrigation mapping undertaken in 2013
Marvellous Midlands	
1. Areas mapped as "Services and Utilities" in DPIPWE (2010) Land Use layer	As given in 2010 Land Use layer
2. Areas within 50m of major tributaries*	Other Rural Enterprises (as potential rehabilitation)
3. Areas within the Tasmanian Reserve Estate (DPIPWE 2014)	Conservation
4. Areas that are "back country," i.e., ridgetops, upper slopes, mid slopes and lower slopes (from landforms layer) that are >1 km from a major road	Conservation
5. Areas mapped as "Other Rural Enterprises" using DPIPWE (2010), and which intersect with areas of high conservation value (based on an unpublished conservation prioritisation score developed for DPIPWE by the lead author**)	Conservation
6. Areas mapped as Lowland *Themeda triandra* grassland or Lowland *Poa labillardierei* grassland using TASVEG 3.0 (Kitchener and Harris 2013)	Conservation
7. Landforms mapped as mid slopes, lower slopes, valley fill in upland landscapes and large expanses or in-filled valleys and alluvial depositions	Irrigated Agriculture
8. Areas within 2 km of major tributaries*	Irrigated Agriculture
9. Other areas not affected by above rules	As per the Tasmanian Land Use layer DPIPWE (2010) and pivot irrigation mapping undertaken in 2013

*Major tributaries are defined as river order >5, based on the Conservation of Freshwater Ecosystems layer (DPIPWE 2005). **The conservation prioritisation score was developed for DPIPWE as an index combining spatial data to identify areas with high coincidence of biodiversity features (a "stacking and weighting" approach). Selected biodiversity features and their priority weightings were informed by existing state, national and international policy and environmental legislation. Biodiversity features included: threatened biomes, vegetation, and species, glacial, fire and disease refugia, freshwater ecosystems, and sites with specific biogeographic distinctiveness (e.g. centre of endemism for fauna). More details can be obtained from the lead author. Sources: DPIPWE 2005, 2010, 2014; Gallant and Dowling 2003; Grice 1992; Kitchener and Harris 2013

Table 3
Current and projected area for each land use category under each 2030 scenario

Land use category	Current land use	Death by a Thousand Cuts		Cha Ching		People's Republic of Northern Midlands		Marvellous Midlands	
	2009-10 land use (ha)	2030 area (ha)	*Change (ha)*	2030 area (ha)	*Change (ha)*	2030 area (ha)	*Change (ha)*	2030 area (ha)	*Change (ha)*
Irrigated Agriculture	54,483 (13%)*	89,846 (22%)*	+35,363	179,567 (43%)*	+125,083	128,042 (31%)*	+73,559	240,500 (58%)*	+186,017
Non-irrigated Agriculture	265,777 (64%)*	10,095 (2%)*	−255,681	156,310 (38%)*	−109,466	53,911 (13%)*	−211,866	32,816 (8%)*	−232,961
Other Rural Enterprises	14,239 (3%)*	244,321 (59%)*	+230,082	85 (0%)*	−14,154	157,381 (38%)*	+143,142	8,471 (2%)*	−5,768
Services and Utilities	13,736 (3%)*	13,736 (3%)*	0	13,736 (3%)*	0	13,736 (3%)*	0	13,736 (3%)*	0
Conservation	66,886 (16%)*	57,122 (14%)*	−9,764	65,423 (16%)*	−1,463	62,051 (15%)*	−4,835	119,598 (29%)*	+52,712

*Percentages are of total Tasmanian Northern Midlands bioregion area

irrigation, such as along the foothill slopes. In many cases these foothill areas match those predicted to experience climate conditions conducive for currently endangered grassland ecosystems (Harris et al. 2015). To investigate this possibility further, future analysis could compare the projected future land use maps presented here with other maps identifying conservation priorities. Maps identifying future conservation possibilities have already been developed through the use of species distribution modelling under the influence of projected climate change (Porfirio et al. 2014; Harris et al. 2015). This comparison could identify areas with potential for conservation that are not identified through current approaches to biodiversity prioritisation.

New areas for conservation potential along the foothill slopes are also likely to be seen by future landholders as more useful for conservation than for any other purpose (shown in dark green as 'Conservation' in Figure 5), or for purposes that could potentially co-exist with conservation (shown in light yellow-green as 'Other Rural Enterprises'). Uptake of land management practices conducive to conservation on the foothill margins of the Midlands is already evident, and its future potential well recognised, especially given such practices are able to build on a long history of landholder experience managing livestock grazing of native grasslands (Kirkpatrick and Bridle 2007). Financial or other government support for conservation of 'back country' would probably be contingent on the natural values identified in those areas. Similarly, for the two low farmer profitability scenarios (Figures 5a and 5c), new areas for conservation potential could align with those designated as 'Other Rural Enterprises', possibly becoming the target for purchase for conservation use by government or not for profit organisations.

Another example of a previously unanticipated land use change arose from the narratives for the two scenarios with high human and social capital. Landholder collaboration in water storage and distribution emerged as a plausible response to increased run-off suggested in regional climate modelling (Bennett et al. 2010), resulting from projected increases in extreme rainfall events (White et al. 2010). Collaborative water management could rehydrate floodplains and improve year-round water retention in the landscape (Andrews 2008). A logical focus for this effort would be ephemeral wetlands which hold prospects for restoring ecosystem function and rehabilitating associated native vegetation (identified through the use of Rule 2 for 'People's Republic of Northern Midlands' and 'Marvellous Midlands' scenarios – see Table 2). Some of the equivalent areas in the worst-case scenario may become degraded beyond recovery due to increased waterlogging. In either case, strategies for conserving native grassland and wetland ecosystems in these areas would need to take into account the overall increase and variability in the amount of water in the landscape and identify which local species assemblages would be favoured by such changes.

From these examples, it can be seen that a key contribution of our approach is to visually represent a range of alternative futures that may not have otherwise been considered by land managers planning interventions for biodiversity conservation. The spatial representations of these diverse futures are also a helpful decision support tool for conservation managers seeking to shift their planning strategies to a whole-of-landscape scale, as recommended by recent reviews of biodiversity planning in Australia (Hawke 2009) and the United States (Benson 2012). Such shifts include reconsidering priority locations for conservation effort, identifying opportunities to enhance and connect patches of high natural value, and identifying strategies best suited to enhance biodiversity outcomes in different locations. In some cases, opportunities might arise where conservation efforts can be closely aligned with ecosystem functions sought by landholders, such as better management of increased runoff from the expected higher frequency of extreme events, or by reconnecting less profitable 'back country' to achieve regional scale wildlife corridors. Applying this method to other landscape-scale objectives could provide similar advantages to enhance planning in the face of uncertain and difficult to control futures.

The use of the four-space matrix to generate scenarios that articulate a diverse set of plausible futures has a distinct advantage over other methods used to generate scenarios for spatial representation. In some cases, only one alternative future is represented (Southern et al. 2011), while in others, the range of alternative futures is determined by contrasting future states relating to a single driver of change, such as climate change (e.g. Bryan et al. 2011). In our case, all scenarios were based on a consistent climate change trajectory, with an extreme range of plausible scenarios identified through the intersection of two key drivers of change whose future states were considered by stakeholders to be most important and uncertain. Land managers are thus prompted to consider how to intervene in the system in ways that offer the best prospects for biodiversity across the most diverse range of plausible scenarios. Our approach also enables identification of governance reforms that can plausibly enhance prospects for biodiversity across all scenarios (Mitchell et al. 2016b), as opposed to the approach of Southern et al. (2011), whose focus was on governance reforms to secure one preferred future.

Our approach could be extended to systematically explore the differential effects of key drivers of change across the four scenarios, such as how landholders respond to changing climatic conditions. Representing these visually as future land use maps would enable rapid appraisal of such differences. For example, landholder responses to changing patterns of water runoff and availability will be different across the four scenarios considered in this paper. The scenario involving high levels of human and social capital coupled with high levels of profitability is likely to result in farmers adapting to changed conditions more easily than in other scenarios. It may be possible to spatially represent such variability in adaptive capacity associated with human and social capital across the landscape (Lockwood et al. 2015). The rule set could be modified to incorporate rules representing spatial distribution of potential adaptive capacity into the future, and the resulting insights used to verify or adjust the associated scenario narratives. When rule sets are used, approaches can be developed iteratively with stakeholder input. Assumptions on which the rules are based can be made apparent, discussed and adjusted if required. Testing of these assumptions can lead to modification of rules, or new rules being added, from which new maps can be created.

The novel approach of applying rules sets to readily available spatial data offers a simple, transparent and flexible means of spatially representing land use change from scenario narratives. The approach is readily suited to engaging stakeholders in discussions about future possibilities, and how to plan for them. While the approach may not be as adaptable as approaches that enable changes to be made 'live' in response to discussion (as can be done, for example, through the MCAS-S spatial multi-criteria software – see Mackey et al. 2010; 2016), it allows adjustments to be made to maps that can be interrogated using a limited set of transparent assumptions. New maps can be created based on any adjustments made.

Figure 3 also suggests a number of additional maps that could be created using the same rule sets approach. These could focus on threats to natural values and opportunities to conserve natural values, generating new maps to stimulate stakeholder discussion of conservation strategies best suited to different locations.

The approach also offers the prospect of improving the validity of scenario narratives by testing their spatial representation using simple rule sets. For example, it is possible that a rule set matching a theme emerging from one scenario, such as location of wetlands, cannot be applied to another scenario due to an information gap in the associated narrative. Such a possibility can then prompt the addition of an associated storyline to the narratives to ensure that this particular theme and its spatial implications are represented in all scenarios. This iterative process helps to discipline the task of generating scenario narratives through systematic testing of key themes for consistency across scenarios (Chermack 2007). The process can also serve as a focus for transdisciplinary knowledge exchange and co-production between researchers and research users, and between science and policy (Fazey et al. 2013; Hegger et al. 2014; Pohl 2011). Future applications of the approach would therefore best be undertaken as an iterative process to maximise input and discussion by key stakeholders on scenario design and support an adaptive approach to future planning.

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