Landscape Ecol (2010) 25:1219–1230
DOI 10.1007/s10980-010-9494-x

RESEARCH ARTICLE

Integration by case, place and process: transdisciplinary research for sustainable grazing in the Lachlan River catchment, Australia

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Received: 9 August 2009 / Accepted: 27 May 2010 / Published online: 11 June 2010

Abstract In a context of global agricultural intensification, integrating conservation and agricultural production is a major challenge. We have tackled the problem using a transdisciplinary research framework. Our work focuses on part of the upper Lachlan River catchment in southeastern Australia. The region is dominated by livestock grazing, and is part of an internationally recognised threatened ecoregion because most native woodland vegetation has been cleared. In productive areas, most remnant vegetation occurs as scattered and isolated paddock trees, which are dying from old age and not regenerating due to agricultural practices. The policy context and industry trends present additional risks for sparse trees. These declining trees provide many ecosystem services, including enhanced water infiltration, shade for livestock, aesthetic and cultural values, and habitat for native species. Our research aims to identify management options and policy settings that enable landscape-scale tree regeneration while maintaining grazing production. Our findings highlight tensions between the trajectory of tree cover in the region and stakeholder values. Under status quo management, many scattered and isolated paddock trees will be lost from farms, although most farmers would like to see them persist. Case studies on selected farms reveal management strategies that may be more sustainable in terms of tree regeneration and agricultural productivity, such as rotational grazing. In addition to these applied insights, our work provides a case study illustrating how a transdisciplinary study can be conducted efficiently by a small team. Our pragmatic approach has successfully combined targeted disciplinary activities with strategic collaborations and stakeholder engagement, all united by shared landscape, case graziers, and outreach activities.

Keywords Fertiliser use · Landscape restoration · Rotational grazing · Scattered trees · Sustainable grazing · Transdisciplinary research · Tree decline

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Introduction

Worldwide, natural ecosystems have been modified to make space for agricultural production (Foley et al. 2005; Tscharntke et al. 2005). Forests and woodlands have been severely impacted (Hoekstra et al. 2005), partly because trees compete directly with agricultural production. At the global scale, livestock grazing is the most widespread form of land use by geographical extent (Asner et al. 2004), and its extent and intensity may further increase with a growing human population and demand for protein (Tilman et al. 2002). The maintenance of trees and livestock grazing may be compatible because trees provide some production benefits, such as shade for livestock and potentially enhanced pasture growth (Bird et al. 1992; Walpole 1999). It may thus be possible to integrate conservation and production in grazing areas to the benefit of agro-ecosystems around the world.

Australia's grazing landscapes comprise 85% of Australia's agricultural production areas and 56% of the country as a whole (Beeton et al. 2006; ABS 2007a). In Australia's southeastern temperate sheep-wheat belt, the trees that survived clearing during settlement—often the oldest trees in the paddocks at the time—now represent the top end of an upwardly skewed age profile (Fischer et al. 2010). These remaining old trees are now dying after having failed to produce viable seedlings because of grazing pressure and competition with introduced pasture species (Dorrough and Moxham 2005; Gibbons et al. 2008a). The process of tree regeneration has been neglected in management and policy, despite the fact that a regional-scale collapse in tree cover poses many risks for the services provided by trees for biodiversity, commodity production and human well-being, and for overall ecosystem resilience (Manning et al. 2006; Vesk and MacNally 2006). Australia already possesses a highly variable climate, and without paddock trees, the resilience of ecosystems to climate change will be further reduced (Manning et al. 2009). The tree regeneration crisis of the south-eastern temperate wheat-sheep belt is of global significance due to the region's status as an internationally recognised threatened ecoregion (Hoekstra et al. 2005).

Although protected areas exist in Australian grazing landscapes (e.g. 3% of our study area), protection is strongly biased towards upper topographic positions (Pressey et al. 2000). Private landholders largely control the future of trees in the lowlands. Finding the means to allow production and conservation to co-exist requires insight into the biophysical and socioeconomic drivers and outcomes of native vegetation management among landholders. Agricultural producers make their farming decisions carefully: typically residing in their working landscapes, they experience deeply the impacts of their decisions. Few landholders would consciously choose a treeless future. Stated values about the environment, however, are frequently inconsistent with landholder behaviour (Vanclay 1992; Cary 1993; Hodgkins et al. 1999; Jurin and Fortner 2002; Lawrence et al. 2004). For graziers, the complexity of the agricultural context makes it difficult to balance the many competing pressures and priorities in their decision-making (Pannell 2003; MacLeod and McIvor 2006; Crosthwaite et al. 2008; House et al. 2008). As a result, landholders often end up sacrificing one spatial or temporal scale for another. For instance, conservation practices that address farm-scale productivity issues have typically been more readily adopted than practices that address larger scale issues such as soil salinity and biodiversity loss (Pannell et al. 2006). Similarly, positive returns from conservation activities tend to accrue over the long term while the costs of implementation are incurred in the short term (Barr and Cary 1992). New practices are a gamble in a changeable regulatory, industry and environmental context, and not all changes are readily 'trial-able' to reduce that risk (Schirmer et al. 2000; Pannell et al. 2006). Understanding the complex socioeconomic and biophysical interactions that underpin alternative landscape futures, and achieving real change, requires transdisciplinarity: a research approach that is interdisciplinary, integrated and participatory (Naiman 1999; Fry 2001; Carpenter and Folke 2006).

The theoretical basis for transdiscplinary research is growing (Fry 2001; Tress et al. 2003; Hadorn et al. 2006; Wu 2006). In this paper, we describe how we have implemented a transdisciplinary research framework in the 'Sustainable Farms' grazing landscapes project. 'Sustainable Farms' aims to identify the grazing management practices that provide the best chance of regenerating trees, and estimate the aesthetic, monetary and biodiversity benefits of using them. We show that: (1) there is a mismatch between how stakeholders value on-farm vegetation and its current decline; (2) there are feasible means to reverse that trajectory while maintaining production; and, (3) a pragmatic integration approach can make transdisciplinarity possible for small research teams working under short time horizons.

Conceptualising integration

Difficulties in working across disciplines begin with language (Antrop 2003; Tress et al. 2005; Wu 2006). The term 'multidisciplinarity' describes a cluster of individuals using their disciplinary expertise on a common problem, without ever integrating their insights. If multiple theories and methods are being combined to form a research approach, it is typically termed 'interdisciplinary' (Tress et al. 2005). Some multidisciplinary and interdisciplinary work is 'applied', meaning that it seeks to achieve change. Applied landscape research requires a participatory approach in which potential agents of change are actively involved in the research process. This is known as 'transdisciplinarity', where stakeholders outside of traditional academic settings are recruited into research and decision-making processes (Tress et al. 2005). 'Sustainable Farms' is transdisciplinary, in that the team seeks not only to work across disciplines, but reach outside the university walls to collaborate with graziers and the policy community. Integrating disciplines and stakeholders in research both hold practical challenges (see, for instance, Naiman 1999; Fry 2001; Antrop 2003).

First, although it is widely accepted that expertise from a range of disciplines is needed in sustainability research, too much diversity in research teams can be detrimental to progress (Melin 2000; Barjak 2006). Shared research interests do not necessarily lead easily to shared means to research them (Lele and Norgaard 2005). Also, translation is often needed to ease the communication problems that result from clashes of scholarly paradigms. Such translation can be facilitated, for example, by a common place of study (e.g. environmental history; see Pawson and Dovers 2003), unit of measurement (e.g. probability; see Cain et al. 2003), or modelling language (e.g. system dynamics; see Vennix 1999). The problems that arise when trying to validate interdisciplinary research, such as choosing a scale of analysis, pursuing peer review and defining what constitutes burden of proof, are more intractable. Nascent disciplines that arise in the interstices of other fields, like landscape ecology, take time to establish mature research paradigms (Moss 2000; Wu 2006). Individual contributors must thus undertake research towards the common goal that meets the rigours of their own respective fields (Daily and Ehrlich 1999). This outward focus can distract from the task of integration.

Second, integrating stakeholders into the research process is essential when aiming to influence behaviour or policy but also entails risk. The trend towards embedding research into society has been termed 'post-normal' or 'Mode 2' science (Funtowicz and Ravetz 1993; Gibbons et al. 1994) and presents challenges particularly to small projects. Large research groups or programs like Australian Cooperative Research Centres have the resources and long time horizons necessary for iterative and adaptive participatory research, where stakeholders are integral to the project design as well as execution (Dovers 2005; van Kerkhoff 2005; Duff et al. 2009; see also Bohnet in this volume). By contrast, small research teams with short timeframes must maintain an achievable research scope and so operate with tight constraints with respect to stakeholder engagement. Our work falls in this latter category; our stakeholders have been invited to shape the research agenda during yearly workshops, but otherwise their involvement has been limited to hosting case sites and acting as subjects in social science methodologies (Dovers 2005).

Methods

'Sustainable Farms' focuses on the long-term ecological integrity and agricultural productivity of rural landscapes, adding policy and social dimensions to solution-oriented ecological research. In April 2008, we held a scoping workshop for the project, and in collaboration with stakeholders formulated three overarching research questions (Sherren et al. 2008b):

1. Which management practices will achieve balanced production, aesthetic and ecological goals?
2. What is the likely future for landscapes in the region under current or alternative grazing practices?
3. How can the public and private benefits and tradeoffs for vegetation management be handled?

We first introduce the study area, and then provide an overview of the disciplinary methods employed. We then integrate and synthesise the results from individual activities to address our three overarching questions. We conclude with practical recommendations for transdisciplinary research drawn from our experiences.

Study area

Our study area encompasses one million hectares in the upper Lachlan catchment of New South Wales (NSW), Australia (Fig. 1). Farming of sheep, beef

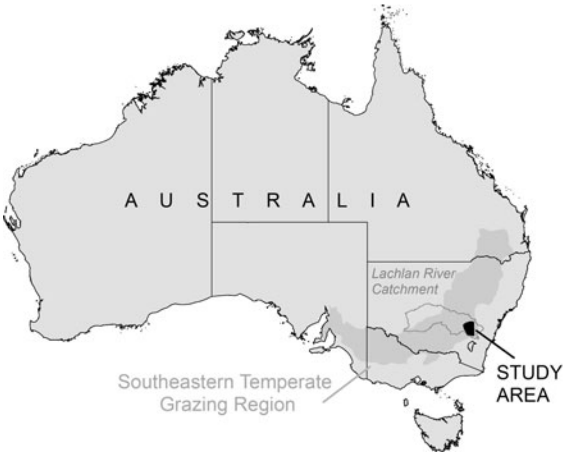

Fig. 1 Map of the study area

cattle and grain are the key industries. In 2006, these industries together employed 11.7 and 36.6% respectively of the workforce in the Cowra and Boorowa census districts core to the study area (compared with 1.5% Australia-wide; ABS 2007b, c). In 2006, 55% of the region's AUD$130.6 million worth of production came from livestock, but grazing is considerably more dominant on the basis of area (e.g. 72.5% of our study area, compared with 12.5% cropping). When 'Sustainable Farms' began in mid-2007, landholders were facing a challenging context for grazing and restoration activities, including 7 years of drought conditions, increasing costs of farm inputs, and declining commodity prices.

As is typical for many rural communities, the region's population is aging more rapidly than the Australian average, with 5% more people aged 65 and over than the general Australian population, and 6% fewer of the 'working' ages of 25–64 (ABS 2007b, c). The average age of farmers in the Lachlan catchment has increased from 48 in 1996 to 51 in 2003 (LCMA 2006). This aging demographic may be even more pronounced for the landholders of interest to the project; nationwide, graziers are typically older than croppers (Barr 2004).

The eastern side of the study area is hilly and rocky in parts (locally referred to as 'granite country'), and livestock grazing is the only viable agricultural

Fig. 2 Sample images of the study area, captured by landholders during the photo-elicitation research. The photos illustrate **a** the rugged, rocky terrain of the eastern side (photo: Jane Campbell), and **b** the gentle country of the west, with some cropping activities (photo: David Marsh)

activity (Fig. 2a). Further west, slopes are gentler and the amount of cropping increases (Fig. 2b). The study area used to be dominated by grassy box woodlands in the valleys (dominated by yellow box (*Eucalyptus melliodora*), Blakely's red gum (*E. blakelyi*), white box (*E. albens*)), and dry forest communities on the ridges (dominated by red stringybark (*E. macrorhyncha*)). Today, regional tree cover is 17.5% (including public reserves). Large patches of trees (>5 ha) are largely confined to the hilltops, but scattered paddock trees are common throughout the region, and account for approximately one-third of the remnant tree cover on farms (Fischer et al. 2010). Thirty-three farms were chosen as research cases to sample a wide range of stocking densities and stock rotation regimes. While a few landholders undertook some cropping, the biophysical study focussed on grazing alone.

Disciplinary techniques

Our five-member research team comprises expertise in ecology, economics and farm finance, policy analysis, spatial science, and social and participatory research methods. This group is divided into three distinct research components (biophysical, policy/economics and social/values) each operating autonomously to ensure progress, but with clear points of overlap and symbiosis (Fig. 3). The only dependency was upon the findings of the biophysical component (which began earlier) to narrow the scope of desirable interventions for the policy and economic research and the visualisation of landscape futures. Key methods used in the three components to date are briefly summarised below.

A field ecological approach was used to correlate grazing management histories given by landholders with biodiversity and the likelihood of tree regeneration (see Fischer et al. 2009c for details). Briefly, four types of survey sites were established: grazed woodland, ungrazed woodland, scattered trees and isolated paddock trees. At all sites, trees were counted and their diameters were measured, and soil samples were taken to assess nutrient loads. In two subsequent years, seedlings were counted and birds were surveyed. In the second year, bats were surveyed (Fischer et al. 2009b). These data will

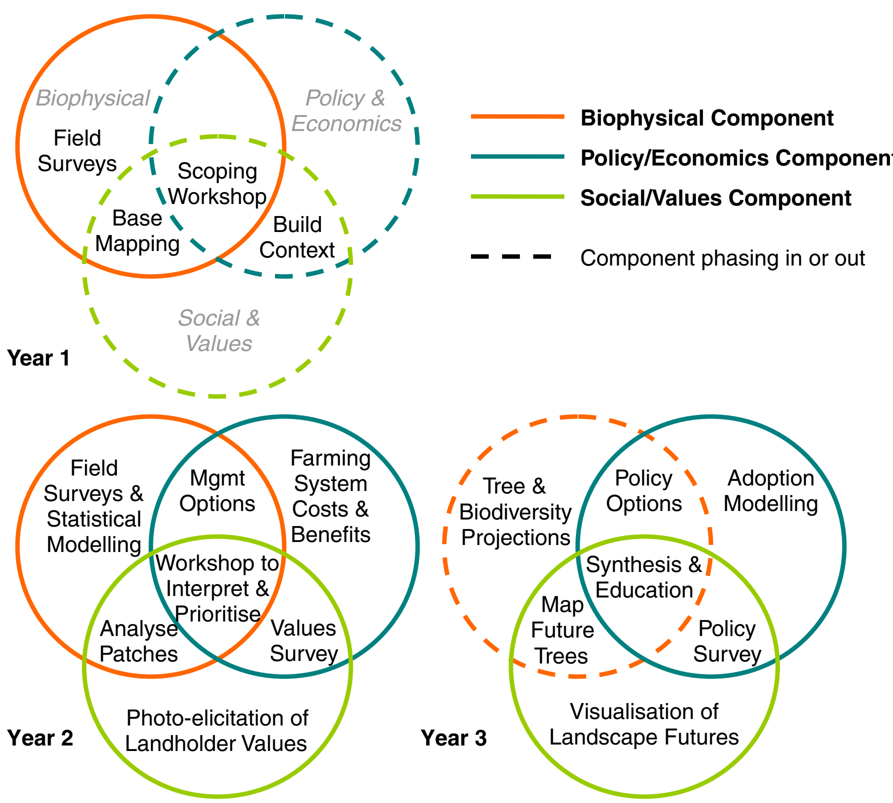

Fig. 3 Venn diagrams summarising individual component activities, and overlaps where collaboration has occurred, for each year of the project

enable the projection of tree cover and biodiversity into the future.

Photo-elicitation was used to explore how landholders view trees and other elements of their working landscapes, and how their values affect their farm management decisions (Sherren et al. 2010, in press). This involved sending disposable cameras to landholders, for them to capture 'significant' farm features (e.g. Fig. 2). The resulting photographs were used to stimulate discussion in qualitative interviews, based on locally-held rather than externally-imposed values (Sherren et al. 2010). Several of these photos will form the basis of future landscape visualisations.

We held additional interviews with the subset of landholders whose farm management practices were found in the biophysical component of the research to favour the regeneration of scattered trees. We asked them about their farming systems, and the tradeoffs involved with balancing production and conservation goals in the context of change in industry, policy and environmental conditions. This information will be used to evaluate the financial impacts of conservation scenarios over the short and long term.

To extrapolate case-based insights to the larger grazier community, we: (1) collaborated with several other agencies to deliver a survey to Lachlan catchment landholders (62% returned of 1429 sent; 397 from our study area), which explored the values held, and the management approaches used, on different structures of native vegetation (e.g. scattered trees, linear strips, patches) (unpublished data); (2) held two stakeholder workshops to first guide the research (Sherren et al. 2008a, b), and then analysed and interpret its preliminary findings (Clayton et al. 2009); and, (3) synthesised industry and demographic trends from data collected by the Australian Bureau of Statistics. A second survey is currently in train to explore policy alternatives and adoption issues.

Finally, we used spatial analysis at various stages of our work. For example, we compared high resolution maps of woody vegetation and landscape position to analyse spatial patterns in tree cover across the landscape (Fischer et al. 2010). We also mapped case farms to the paddock scale, in collaboration with their owners. In an exploratory extension to the research, those property maps were used in combination with 'viewsheds'—the places visible from each of the photos captured in the photo-elicitation described above—to analyse the amount of woody vegetation landholders photographed relative to their opportunity to do so (Sherren et al. in press).

Research integration

The integration of discipline-specific research activities with each other and with stakeholders has been managed pragmatically in our research. Fundamentally, each component has operated relatively autonomously, with overlaps or dependencies carefully mapped in advance (Fig. 3). Individual activities were carried out through academic publication to meet the standards of the respective disciplines involved. This lends credibility to the integrated outputs. The small size of our research team and their co-location also provided for efficient and effective integration by enabling frequent communication and transparent critical engagement (Barnett et al. 2003): a wholly committed team of five can work together more productively than 50 geographically dispersed individuals contributing 10% each.

We have experienced few difficulties in communication between disciplines because of our strategy of using place, case and process as a shared language. Firstly, all components use the same study area, which is broadly typical of the south-eastern temperate wheat-sheep belt as a whole. Second, the 31 landholders (owning 33 case properties) chosen by the biophysical researchers are, with their permission, also involved with the socioeconomic research. Contact details, management histories and property maps were shared within the project, accelerating progress for the socioeconomic researchers, and the socioeconomic researchers in return enriched the pictures collectively emerging of each case. These shared components allowed us to recognise linkages and triangulate key findings while still working largely in parallel.

Finally, our three research components have come together to jointly hold stakeholder workshops, and to engage with the policy community. For instance, we have discussed our early findings with the government department responsible for a relevant environmental stewardship program to help inform the implementation of their incentive scheme. We also made a submission to a government inquiry on helping farmers adapt to climate change, presenting early findings about the apparent benefits of holistic resource management (a type of high intensity, short duration grazing) for improving farm resilience to variable weather patterns (Fischer et al. 2009a), and were invited to give evidence as a result. Each such activity is an opportunity for the team to integrate their findings, as well as to make a practical difference over a time scale that academic publication alone could not achieve.

Results

The age profile of trees in the study landscape is heavily skewed towards old trees. In typical scattered and isolated paddock tree sites, which make up the majority (~75%) of our study area, trees average at least 120 years in age and often none are younger than several decades old (Fischer et al. 2009c). Trees in these locations are unlikely to regenerate under conventional practices such as continuous grazing and fertiliser use (Fischer et al. 2009c).

Our regional landholder survey demonstrated the scale of the lack of protection afforded to existing scattered paddock trees. Fewer than 10% of landholders in the Lachlan catchment who have scattered trees on their property fenced them off from livestock, compared with 21–23% of those who have small or large patches, and 40% of those who have strips of trees (unpublished data). In addition, only a quarter (27%) of survey respondents with scattered paddock trees had encouraged their regeneration, lower than the percentage with denser arrangements of trees they actively regenerated (41–51%) (unpublished data). This is consistent with the photo-elicitation interviews, where farmers described protecting patches, and planting strips along fences and rivers, while simply grazing around scattered trees (Sherren et al. 2010). Landholders reported during photo-elicitation that financial incentives were very important drivers of their planting and protection activities (Sherren et al. 2010), and these behaviours reflect the current policy environment. Current government incentives, for instance, preference the preservation of large patches, which tend to occur in the non-productive upland settings that make up only 10% of the landscape, rather than the intensively grazed lowlands comprising the remainder of tree cover (Fischer et al. 2010). Other incentives fund permanent fencing and seed mixes for the establishment of linear plantations along fences and drainage lines (Sherren et al. 2010). Such measures, however, are unlikely to result in landscape-wide restoration (Fischer et al. 2008; Wiens 2009).

Land use trends further threaten tree cover. Agricultural statistics show that recent years have seen widespread land use change from sheep grazing to cropping in many parts of Australia, including the study region (ABS 2007b, c). This change has been driven by a range of factors including rising input prices, relative labour scarcity, changing technology and favourable commodity prices for crops relative to livestock products (Clayton et al. 2009). Farmers are also shifting to producing more hay and silage for on-farm use, sometimes in response to drought and scarcity of feed, and the high cost of purchasing it. For example, in NSW, on farm production of silage more than doubled between 2000–2001 and 2006–2007, from 212,683 to 494,025 ha (ABS 2007b, c), now comprising almost a tenth of all cropping activities by area. Land use changes from grazing to cropping can threaten paddock tree survival, because the large equipment and practices commonly used for cropping (e.g. centre-pivot irrigation, GPS-directed machinery) encourage the removal of scattered trees (Maron and Fitzsimons 2007; Gibbons et al. 2009).

Native vegetation management is influenced by the day to day environmental and financial pressures facing farm managers in their enterprise (Clayton et al. 2009). Ongoing drought was the most prevalent influence nominated by survey respondents (85% of them) as affecting their ability to manage native vegetation on their property (unpublished data). Consistent with industry statistics (ABS 2008), the next most common response was financial hardship (81%) (unpublished data). In fact, the aging rural population and declining interest of the next generation in entering farming careers (Kaine et al. 1997) sometimes leads to 'superannuation farming', whereby landholders close to retirement try to eke out the maximum short-term profits before selling their properties (Sherren et al. 2008a). In the case study interviews involving 12 of the innovative graziers targeting regeneration, the capital resources required to meet up-front transition costs (e.g. fencing, stock water infrastructure) were identified as significant constraints to their adoption of more sustainable grazing regimes (Clayton et al. 2009). These innovators commonly sought to increase income stability and reduce input and capital costs to offset any production losses resulting from their conservation activities.

Landholders value trees (Sherren et al. 2010, in press). During the photo-elicitation process, trees made up over a third (35%) of the 'significant' targets that landholders photographed. Of mature trees, sparse arrangements were targeted twice as often as woodlands and patches (Sherren et al. 2010). The 'viewsheds' of landholder photos, calculated using GIS, also captured a larger proportion of woody vegetation than farms overall hold (e.g. a median of 2.2 times more for paddock trees) (Sherren et al. in press). Most of those surveyed (>75%) recognised the value of native vegetation in their landscapes for habitat, aesthetics, and stock protection, and more generally for soil stability, groundwater control, and overall ecosystem health (unpublished data). A similar set of values were prompted by images of trees during the photo-elicitation process (Sherren et al. 2010).

Finally, based on the photo-elicitation interviews, landholders appear highly aware of the decline in scattered paddock trees, and concerned about its impacts (Sherren et al. 2010). Forty-five percent of survey respondents have noticed decreases in their isolated paddock trees, compared with 19% or less of other vegetation structures (such as patches or corridors of trees) (unpublished data). Over half of respondents (51%) believe that the benefits of native vegetation outweigh the costs (e.g. weed and pest management, fire, obstacles to farm equipment), and that landholders are obliged to protect their native vegetation for the benefit of the wider community (58%). Graziers were significantly more likely than croppers to agree with these two statements ($P < 0.01$, ANOVA) (unpublished data), further demonstrating the risk to paddock trees of market trends towards increased cropping.

Discussion

Our findings reveal a clear mismatch between the value stakeholders place on native vegetation and the declining trajectory of tree cover in the region. However, we have identified practical solutions to reversing tree decline at a landscape scale that are compatible with grazing production. There are many places where natural tree regeneration is unlikely to occur, for example due to high soil fertility or a lack of parent trees. In such situations, active approaches may have to be used, such as planting and protecting scattered trees with individual guards or excluding livestock from entire paddocks for extended periods following the direct-seeding of trees (Table 1) (Fischer et al. 2009c). Once a seed source is assured, natural regeneration can be greatly enhanced by lowering soil nutrient levels, to which Australian native tree species are ill-adapted and which allow introduced pasture grasses to outcompete seedlings (Semple and Koen 2003), and using high-intensity, short-duration rotational grazing (Fischer et al. 2009c) (Table 1). Unlike continuous grazing, rotational grazing incorporates prolonged rest periods, thereby allowing pastures and tree seedlings to recover from grazing events.

Our interviews with farmers have also suggested that there may be additional benefits of low-input rotational grazing (see also Richards and Lawrence 2009). For example, farmers who had adopted these practices suggested they now experienced lower financial and environmental risks than previously,

Table 1 Management options to address scattered and isolated paddock tree loss in grazing landscapes (adapted from Fischer et al. 2009c)

Active management	Passive management
1. The planting of trees in a scattered pattern within grazed pastures by using individual tree guards, themselves reusable once seedlings are tall enough to withstand grazing	1. Increased uptake of high-intensity, short-duration rotational grazing
2. The exclusion of livestock from entire paddocks before reseeding paddocks at low densities and resting them until trees have been established	2. A drastic reduction in fertiliser use

Active options refer to tree planting and direct seeding, and are recommended where natural regeneration is unlikely to occur, e.g. due to a lack of seed or an excess of soil nutrients. Passive options encourage the conditions for natural regeneration to occur, and are more likely to lead to landscape-wide tree restoration (see also Dorrough and Scroggie 2008) which had improved the viability of their farms (Clayton et al. 2009; Sherren et al. 2010). Assuming these responses reflect the true benefits of low-input rotational grazing, these benefits can be expected to further increase if the region experiences climate change in the future (Fischer et al. 2009a).

In the survey, a majority of landholders listed their own knowledge, and government policies and support, as influences on their vegetation management decisions (unpublished data). In seeking information on how to manage native vegetation, most landholders reported being influenced by other landholders, agencies such as Catchment Management Authorities, the media, and the scientific literature (although their definition of 'scientific literature' may differ from that used by academics). We have leveraged all of these influences and information sources to put our findings into the hands of potential users. We actively publicised our findings with government departments and agencies concerned with primary industries and with the environment, contributing to active policy debates (e.g. Fischer et al. 2009a). Our workshops have galvanised interest among landholders in landscape-scale restoration. For instance, several of our case study graziers have been inspired to plant several hundred new scattered trees. We have also published a handful of collaborative reports (Sherren et al. 2008a; Clayton et al. 2009) and peer-reviewed papers (e.g. Fischer et al. 2009c, 2010; Sherren et al. 2010), informing scholarly debate and practitioners alike. Radio, print and internet media have covered our work, and our use of open-access publication options where possible (e.g. Fischer et al. 2009c) has further helped to broadcast our results to the widest possible audience.

The overall narrative arising from our work, which we have briefly summarised here, is the result of the integration of numerous individual and collaborative activities undertaken by the 'Sustainable Farms' team, facilitated by the shared context. Despite an increasingly rich narrative, important gaps remain in our research. We intend to explore further the impacts of a range of possible restoration scenarios on landscape and fiscal futures, including vegetation, biodiversity, aesthetics, and farm-scale outcomes (for other examples of this kind of work, see Santelmann et al. 2004; Ryan et al. in this volume; Bohnet and Smith 2007). For a range of scenarios including 'do nothing' and our conservation management practices (Table 1), we will: (1) use the ecological data to project tree and biodiversity futures; (2) draw on tree projections to generate realistic future landscape visualisations for a few landholder photos; and (3) evaluate short and long term profitability. We will also use a large-scale survey and census data to further investigate the degree to which findings derived from our cases apply to the larger sheep-wheat belt. Finally, we will—in collaboration with landholders and relevant agencies—integrate all of the above to identify appropriate policy responses. Our photo-elicitation interviews demonstrated that graziers have taken up a number of past and existing conservation-based educational messages and incentive programs (Sherren et al. 2010); our hope is that we contribute to the development of some clear messages and flexible policies appropriate to reversing the decline in isolated and paddock tree cover in grazing landscapes.

Conclusion

Conventional grazing practices have placed Australia's sheep-wheat belt on a path to a future that conflicts with the aspirations of local people, a situation likely to be mirrored in other grazing landscapes world-wide (Gibbons et al. 2008b). A transdisciplinary research framework has allowed us to identify: (1) grazing practices that will balance production goals with societal values and ecological needs, specifically the reversal of landscape-scale tree decline; and, (2) ways to enhance the widespread adoption of more sustainable management practices.

Our transdisciplinary research framework was designed pragmatically because of the small size of our research team and the need to produce results within a short timeframe. Our design involved four characteristics which are directly transferrable to other settings: (1) co-locating researchers to enable frequent communication between those with complementary expertise; (2) engineering a minimum of task dependency to ensure that individual researchers can carry out their respective components somewhat autonomously; (3) establishing clear leadership and responsibilities for each shared activity; and, (4) using shared cases, stakeholders, study area, workshops and outreach processes as efficient catalysts for collaboration.

Acknowledgements This work was funded by the Australian Research Council and the Australian Government Department of Environment, Water, Heritage and the Arts, the latter through a Commonwealth Environment Research Facilities 'Significant Project'. The authors thank the landholders and other stakeholders who have collaborated in this work, and the insights of three anonymous referees. Thanks also go to: Edwina Loxton, Alex Campbell-Wilson and Cate Campbell-Wilson who provided valuable office assistance; Robert Forrester and Jin Yoon for statistical analysis and research design; and, Jerome Pink, Andre Zerger, John Stein and Garth Warren for spatial analysis expertise. Finally, this project could not have proceeded without the professionalism of field ecology research assistant Jenny Stott.

References

ABS (2007a) Australia's environment: issues and trends ABS cat. no. 4613.0. Australian Government, Australian Bureau of Statistics, Canberra

ABS (2007b) Census quickstats—Boorowa (A) (local government area). Australian Government, Australian Bureau of Statistics, Canberra

ABS (2007c) Census quickstats—Cowra (A) (local government area). Australian Government, Australian Bureau of Statistics, Canberra

ABS (2008) Natural resource management on Australian farms—4620.04620.0. Australian Bureau of Statistics, Canberra, p 37

Antrop M (2003) Expectations of scientists towards interdisciplinary and transdisciplinary research. In: Tress B, Tress G, van der Valk A, Fry G (eds) Interdisciplinary and transdisciplinary landscape studies: potential and limitations. DELTA Program, Wageningen, pp 44–54

Asner G, Elmore A, Olander L, Martin R, Harris A (2004) Grazing systems, ecosystem responses, and global change. Annu Rev Environ Resour 29:261–299

Barjak F (2006) Team diversity and research collaboration in life sciences teams: Does a combination of research cultures pay off? 2006-W02. University of Applied Sciences, Switzerland

Barnett J, Ellemor H, Dovers S (2003) Sustainability and interdisciplinarity. In: Dovers SSD, Young M (eds) New dimensions in ecological economics: integrating people and nature. Edward Elgar, Cheltenham, pp 53–76

Barr N (2004) The micro-dynamics of change in Australian agriculture, 1976-2001ABS cat. no. 255.0. Canberra, ACT

Barr N, Cary JW (1992) Greening a brown land: the Australian search for sustainable land use. MacMillan Education Australia Pty. Ltd., Melbourne

Beeton RJS, Buckley KI, Jones GJ, Morgan D, Reichelt RE, Trewin D (2006) Australia: state of the environment report 2006. Australian Government, Department of the Environment and Heritage, Canberra, p 141

Bird PR, Bicknell D, Bulman PA, Burke SJA, Leys JF, Parker JN, Van der Sommen FJ, Voller P (1992) The role of shelter in Australia for protecting soils, plants and livestock. Agrofor Syst 20:59–86

Bohnet I, Smith DM (2007) Planning future landscapes in the Wet Tropics of Australia: a social-ecological framework. Landsc Urban Plan 80:137–152

Cain JD, Jinapala K, Makin IW, Somaratna PG, Ariyaratna BR, Perera LR (2003) Participatory decision support for agricultural management: a case study from Sri Lanka. Agric Syst 76:457–482

Carpenter SR, Folke C (2006) Ecology for transformation. Trends Ecol Evol 21:309–315

Cary JW (1993) The nature of symbolic beliefs and environmental behaviour in a rural setting. Environ Behav 25:555–576

Clayton H, Schirmer J, Price R, Sherren K, Fischer J, Dovers S (2009) Sustainable Farms II: emerging results, interpretations and research priorities—outcomes from the Sustainable Farms mid-term project workshop Australian National University, p 46. http://fennerschool-research.anu.edu.au/sustfarms/downloads/SustFarmsII.pdf

Crosthwaite J, Malcolm B, Moll J, Dorrough J (2008) Future investment in landscape change in southern Australia. Landsc Res 33:225–239

Daily GC, Ehrlich PR (1999) Managing Earth's ecosystems: an interdisciplinary challenge. Ecosystems 2:277–280

Dorrough J, Moxham C (2005) Eucalypt establishment in agricultural landscapes and implications for landscape-scale restoration. Biol Conserv 123:55–66

Dorrough J, Scroggie MP (2008) Plant responses to agricultural intensification. J Appl Ecol 45:1274–1283

Dovers S (2005) Clarifying the imperative of integration research for sustainable environmental management. J Res Pract 1: Article M1, 19 pp

Duff G, Garnett D, Jacklyn P, Landsberg J, Ludwig J, Morrison J, Novelly P, Walker D, Whitehead P (2009) A collaborative design to adaptively manage for landscape sustainability in north Australia: lessons from a decade of cooperative research. Landscape Ecol 24:1135–1143

Fischer J, Brosi B, Daily GC, Ehrlich PR, Goldman R, Goldstein J, Lindenmayer D, Manning AD, Mooney HA, Pejchar L, Ranganathan J, Tallis H (2008) Should agricultural policies encourage land sparing or wildlife-friendly farming? Front Ecol Environ 6:380–385

Fischer J, Sherren K, Clayton H (2009a) Working in tandem with natural variability: new paradigms for livestock grazing in Australia. House of Representatives Standing Committee on Primary Industries and Resources. http://www.aph.gov.au/house/committee/pir/australianfarmers/subs/sub004.pdf

Fischer J, Stott J, Forrester R, Law B, Adams M (2009b) Designing effective habitat studies: quantifying multiple sources of variability in bat activity. Acta Chiropt 11:127–137

Fischer J, Stott J, Zerger A, Warren G, Sherren K, Forrester RI (2009c) Reversing a tree regeneration crisis in an endangered ecoregion. Proc Natl Acad Sci USA 106:10386–10391

Fischer J, Sherren K, Stott J, Zerger A, Warren G, Stein J (2010) Towards landscape-wide conservation outcomes in Australia's temperate grazing region. Front Ecol Environ 8:69–74

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK,

Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science 309:570–574
Fry GLA (2001) Multifunctional landscapes—towards transdisciplinary research. Landsc Urban Plan 57:159–168
Funtowicz SO, Ravetz JR (1993) Science for the post-normal age. Futures 25:739–755
Gibbons M, Limoges C, Nowotny H, Schwartzman S, Scott P, Trow M (1994) The new production of knowledge: the dynamics of science and research in contemporary societies. Sage, London
Gibbons P, Lindenmayer DB, Fischer J, Manning AD, Weinberg A, Seddon J, Ryan P, Barrett G (2008a) The future of scattered trees in agricultural landscapes. Conserv Biol 22:1309–1319
Gibbons P, Lindenmayer DB, Fischer J, Manning AD, Weinberg A, Seddon J, Ryan P, Barrett G (2008b) The future of scattered trees in agricultural landscapes. Conserv Biol 22:1309–1319
Gibbons P, Briggs SV, Ayers D, Seddon J, Doyle S, Cosier P, McElhinny C, Pelly V, Roberts K (2009) An operational method to assess impacts of land clearing on terrestrial biodiversity. Ecol Indic 9:26–40
Hadorn GH, Bradley D, Pohl C, Rist S, Wiesmann U (2006) Implications of transdisciplinarity for sustainability research. Ecol Econ 60:119–128
Hodgkins D, Goldney D, Watson G, Tyson G (1999) The attitudes of landholders to a range of environmental issues, including the values of remnant bushland in the central western region of New South Wales. In: Hobbs RJ, Yates CJ (eds) Temperate eucalypt woodlands in Australia: biology, conservation, management and restoration. Surrey Beatty & Sons, Chipping Norton, pp 336–350
Hoekstra JM, Boucher TM, Ricketts TH, Roberts C (2005) Confronting a biome crisis: global disparities of habitat loss and protection. Ecol Lett 8:23–29
House APN, MacLeod ND, Cullen B, Whitbread AM, Brown SD, McLvor JG (2008) Integrating production and natural resource management on mixed farms in eastern Australia: the cost of conservation in agricultural landscapes. Agric Ecosyst Environ 127:153–165
Jurin RR, Fortner RW (2002) Symbolic beliefs as barriers to responsible environmental behaviour. Environ Educ Res 8:373–394
Kaine G, Crosby E, Stayner R (1997) Succession and inheritance on Australian family farms. The Rural Development Centre, University of New England, Armidale
Lawrence G, Richards CA, Cheshire L (2004) The environmental enigma: why do producers professing stewardship continue to practice poor natural resource management. J Environ Policy Plan 6:251–270
LCMA (2006) Lachlan catchment action plan. Lachlan Catchment Management Authority, p 208. http://www.lachlan.cma.nsw.gov.au/downloads/Catchment_Action_Plan/Lachlan_Catchment_Action_Plan_V9.pdf
Lele S, Norgaard RB (2005) Practicing interdisciplinarity. Bioscience 55:967–975
MacLeod ND, McIvor JG (2006) Reconciling economic and ecological conflicts for sustained management of grazing lands. Ecol Econ 56:386–401
Manning AD, Fischer J, Lindenmayer DB (2006) Scattered trees are keystone structures—implications for conservation. Biol Conserv 132:311–321
Manning AD, Gibbons P, Lindenmayer DB (2009) Scattered trees: a complementary strategy for facilitating adaptive responses to climate change in modified landscapes? J Appl Ecol 46:915–919
Maron M, Fitzsimons JA (2007) Agricultural intensification and loss of matrix habitat over 23 years in the West Wimmera, south-eastern Australia. Biol Conserv 135: 587–593
Melin G (2000) Pragmatism and self-organisation: research collaboration on the individual level. Res Policy 29:31–40
Moss MR (2000) Interdisciplinarity, landscape ecology and the "Transformation of Agricultural Landscapes". Landscape Ecol 15:303–311
Naiman RJ (1999) A perspective on interdisciplinary science. Ecosystems 2:292–295
Pannell D (2003) Balancing economics and sustainability in building an integrated agricultural system. Pac Conserv Biol 9:23–29
Pannell DJ, Marshall GR, Barr N, Curtis A, Vanclay F, Wilkinson R (2006) Understanding and promoting adoption of conservation practices by rural landholders. Aust J Exp Agric 46:1407–1424
Pawson E, Dovers S (2003) Environmental history & the challenges of interdisciplinarity. Environ Hist 9:53–75
Pressey RL, Hager TC, Ryan KM, Schwarz J, Wall S, Ferrier S, Creaser PM (2000) Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia. Biol Conserv 96:55–82
Richards C, Lawrence G (2009) Adaptation and change in Queensland's rangelands: cell grazing as an emerging ideology of pastoral-ecology. Land Use Policy 26:630–639
Santelmann MV, White D, Freemark K, Nassauer JI, Eilers JM, Vaché KB, Danielson BJ, Corry RC, Clark ME, Polasky S, Cruse RM, Sifneos J, Rustigian H, Coiner C, Wu J, Debinski D (2004) Assessing alternative futures for agriculture in Iowa, U.S.A. Landscape Ecol 19:357–374
Schirmer J, Kanowski P, Race D (2000) Factors affecting adoption of plantation forestry on farms: implications for farm forestry development in Australia. Aust For 63: 44–51
Semple WS, Koen TB (2003) Effect of pasture type on regeneration of eucalypts in the woodland zone of south-eastern Australia. Cunninghamia 8:76–84
Sherren K, Dovers S, Fischer J, Schirmer J (2008a) Sustainable Farms I: indentifying leverage points for reversing paddock tree loss—background and scoping workshop results Australian National University, p. 34. http://fennerschool-research.anu.edu.au/sustfarms/downloads/SustFarmsIfinal.pdf
Sherren K, Fischer J, Dovers S, Schirmer J (2008b) Leverage points for reversing paddock tree loss in Upper Lachlan grazing landscapes—a workshop report. Ecol Manag Restor 9:237–240
Sherren K, Fischer J, Price R (2010) Using photography to elicit grazier values and management practices related to tree survival and recruitment. Land Use Policy 27:1056–1067

Sherren K, Fischer J, Pink J, Stott J, Stein J, Yoon H-J (in press) Australian graziers value sparse trees in their pastures: a viewshed analysis of photo elicitation. Society and Natural Resources

Tilman D, Cassman KG, Matson P, Naylor R, Polasky S (2002) Agricultural sustainability and intensive production practices. Nature 418:671–677

Tress B, Tress G, van der Valk A, Fry G (2003) Interdisciplinary and transdisciplinary landscape studies: potential and limitations. DELTA Program, Wageningen

Tress G, Tress B, Fry G (2005) Clarifying integrative research concepts in landscape ecology. Landscape Ecol 20:479–493

Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C (2005) Landscape perspectives on agricultural intensification and biodiversity—ecosystem service management. Ecol Lett 8:857–874

van Kerkhoff L (2005) Integrated research: concepts of connection in environmental science and policy. Environ Sci Policy 8:452–463

Vanclay F (1992) Barriers to adoption: a general overview of the issues. Rural Soc 2:10–14

Vennix JAM (1999) Group model-building: tackling messy problems. Syst Dyn Rev 15:379–401

Vesk PA, MacNally R (2006) The clock is ticking—revegetation and habitat for birds and arboreal mammals in rural landscapes of southern Australia. Agric Ecosyst Environ 112:356–366

Walpole SC (1999) Assessment of the economic and ecological impacts of remnant vegetation on pasture productivity. Pac Conserv Biol 5:28–35

Wiens JA (2009) Landscape ecology as a foundation for sustainable conservation. Landscape Ecol 24:1053–1065

Wu JG (2006) Landscape ecology, cross-disciplinarity, and sustainability science. Landscape Ecol 21:1–4