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Enhancing and utilising landscape heterogeneity to meet multiple land use objectives

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Enhancing and utilising landscape heterogeneity to meet multiple land use objectives

Final Report (June 2009)

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Abstract

The broad aim of the project was to provide land managers with information that will encourage them to further value, protect and enhance vegetation diversity by demonstrating the practical benefits that can be derived from this natural asset in Australian rangelands. Vegetation diversity and local climate influences combine to produce differences between regions in the patterns of plant growth from year to year, such that the timing of droughts and favourable years can vary between regions. We set out to determine how geographical diversification in rangelands could exploit such non-synchronous patterns of plant production to buffer the effects of drought and reduce exposure to risks associated with climate variability using strategic networks of jointly-managed properties. The project has:

1. Developed methods for quantifying beneficial aspects of diversity in native vegetation, particularly those that could be used to diversify climate variability risks, reduce exposure to drought impacts and buffer temporal variability in access to the goods and services provided by rangelands.

2. Quantified beneficial patterns of non-synchronous plant growth in rangelands and provided them in a form (including an interactive HTML tool) that could assist land managers in decision making, particularly how regional scale vegetation diversity can be used to structure networks of pastoral properties to diversify and reduce the risks associated with climate variability.

3. Together with land mangers, raised awareness of the practical benefits of vegetation diversity (for both animal production and wider environmental and ecosystem service objectives) and options for maintaining this resource (with particular reference to managing the damaging impacts of climate variability).

These same principles should have wide relevance and could be applied, for example, to rain-fed crops, designing the arrangement of conservation areas, and managing reservoir populations of pests and diseases.

Summary

Background

Vegetation diversity and local climate influences combine to produce differences between regions in the patterns of plant growth from year to year, such that the timing of droughts and favourable years can vary between regions. Over the years, the spatial heterogeneity of resources available to livestock and land managers has been reduced by subdivision of rangelands into separated enterprises, and by intensification within properties. This trend is now reversing through property consolidation and increased use of agistment.

Decisions on the selection of additional pastoral properties are made in isolation of how spatial heterogeneity could be used to better manage and buffer temporal variability. However, an opportunity is being missed. It should be possible to reduce the exposure of pastoral enterprises to the risks associated with climate variability by pairing together properties where drought and favourable seasons occur in different years. This should alleviate the problems of rangeland degradation often associated with the challenges of drought and climate variability. If pastoralists are able to recognise, value and utilise the benefits of vegetation diversity in buffering the effects of climate variability, then they may be better able to maintain the condition of their land during drought, including vegetation diversity and the benefits it provides.

While these principles of diversifying risk spatially to offset climate variability have long been recognised, the challenge has been to quantify this information in a form that can be used to inform management decisions. Addressing this challenge was the main rationale and goal of this project. As the pastoral industry is going through a phase of property consolidation (after a previous history where policies have led to the subdivision and fragmentation of properties) this seems like an opportune time to consider the full range of synergistic benefits that can be gained by taking advantage of complementarities between properties. The main basis of our approach was to identify groupings of pastoral properties where fluctuating patterns of plant growth and the timing of droughts are as different as possible. In conjunction with land managers we developed and demonstrated analytical tools to assist pastoralists in deciding how groups of properties might be best located geographically to help minimise the impacts of climate variability and avoid some of the current problems associated with declining native vegetation condition during drought. The broad aim of the project was to provide land managers with information that will encourage them to further value, protect and utilise vegetation diversity by demonstrating the practical benefits that can be derived from this natural asset in Australian rangelands.

Delivery against objectives

The three objectives planned and achieved by the project were:

1. To develop methods for quantifying beneficial aspects of diversity in native vegetation, particularly those that could be used to diversify climate variability risks,

reduce exposure to drought impacts, and buffer temporal variability in access to the goods and services provided by rangelands;

2. To quantify beneficial patterns of non-synchronous plant growth in rangelands and provide them in a form (including an interactive HTML tool) that could assist land managers in decision making, particularly how regional-scale vegetation diversity can be used to structure networks of pastoral properties to diversify and reduce the risks associated with climate variability;

3. Together with land mangers, to raise awareness of the practical benefits of vegetation diversity (for both animal production and wider environmental and ecosystem service objectives) and options for maintaining this resource (with particular reference to managing the damaging impacts of climate variability).

The overall research approach was to engage with a group of participating pastoralists with multiple-property enterprises to develop and evaluate analyses and information tools that could assist them to explore the exposure of their enterprises to the risks of climate variability; evaluate how well their existing holding of properties diversified these risks; and identify potential opportunities where new properties could be bought (and existing properties sold) to enhance the benefits of geographic diversification. The project achievements against each of the three objectives are summarised below. The full report contains a more detailed account of the project activities and findings.

Objective 1. Develop methods for quantifying beneficial aspects of vegetation diversity

The first methodological challenge was to develop an approach to quantify the benefit of grouping together properties with complementary patterns of year-to-year variation in plant growth. While correlation between time series seemed like an obvious first choice, it was prone to artefacts and abandoned. Instead, we defined the benefit that we wanted to quantify in terms of the principle of trying to group properties together in such a way that year-to-year variation in plant growth as a proportion of the average total annual plant growth across the combined properties was as low as possible (i.e. minimising the temporal co-efficient of variation, or risk, for the combined group of properties). Based on this principle, we identified two measures for quantifying complementary patterns of year-to-year variation in plant production.

The first metric measured how an existing property or group of properties in an enterprise would benefit by adding another property to that enterprise. This was quantified as the coefficient of variation benefit (CVB) which measured the decline in the temporal coefficient of variation in plant production resulting from adding a new property to an existing pastoral enterprise (see full report for details). The second metric measured the benefit within a group of properties, relative to the variation that individual properties would be exposed to if treated as separate entities. The within-group variance benefit (WVB) for a group of properties was measured as the sum of standard deviations for temporal variation in plant production for the component properties minus the standard deviation of the combined sum of plant production combined across properties. This term was then standardised by dividing by the average annual plant production for the group of properties (see full report for details).

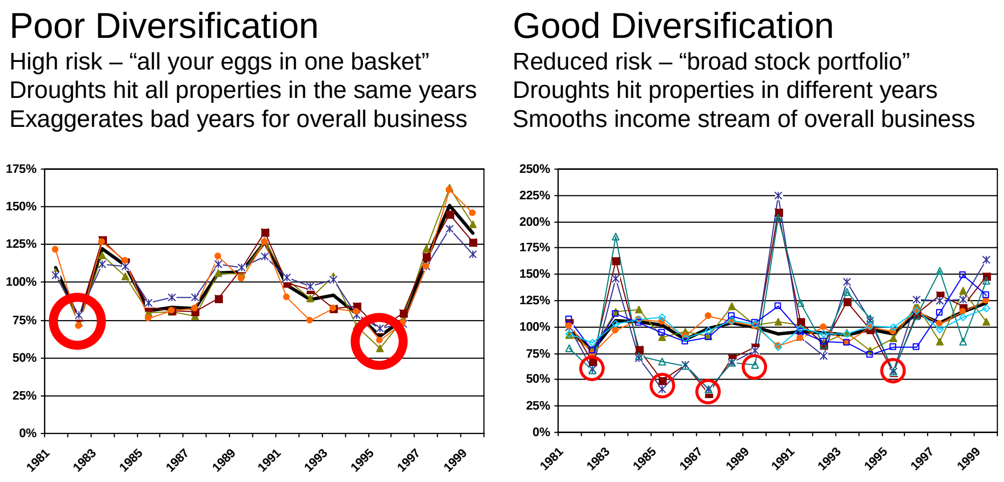
The second major methodological issue was deciding on appropriate data sets to capture combined spatial (property-to-property and region-to-region) and temporal (year-to-year) patterns of variation in plant growth. There were two main sources of data, each with different strengths and weaknesses: a) data derived from time sequences of satellite imagery and b) data derived from weather station records. The best satellite-based data we could obtain was a 20-year time series of global net primary production (NPP) estimates based on NOAA/NASA AVHRR data which had been analysed with the global production efficiency model (GLO-PEM). The best weather-based data we could obtain were AussieGRASS estimates of forage production, which used a grass growth model and spatially interpolated weather station data. These provided estimates of forage growth over the past 120 years across Australian rangelands. Some post-processing of data was done before analysis to eliminate sources of year-to-year fluctuations other than natural plant growth-climate interactions. Analyses were conducted at the property scale (for all pastoral properties across Queensland) and at the regional scale, by dividing the rangelands according to IBRA (interim biogeographic regionalisation of Australia) subregions. For property-scale analyses we judged the satellite-based data to be preferable, because the data was at sufficient spatial resolution to capture the differences in year-to-year patterns of variation at this fine scale. For regional-scale analyses we found it preferable to take advantage of the longer-term patterns of variability captured by the data derived from historical weather records. To handle the very substantial amounts of data and processing involved, all analyses were implemented within a database using SQL (search and query language).

Objective 2. Provide information on beneficial patterns of non-synchronous plant growth in a form that supports management decisions

Several approaches and tools were developed to visualise the output from analyses to help property managers identify vulnerabilities to climate variability and potential options and opportunities to reduce these risks. These were: a) an analysis of the existing property network, b) maps of properties and regions with complementary patterns of year-to-year variation in plant growth (using our CVB score), and c) a web-based interactive HTML tool that can be used to explore complementarities (CVB) between any pair of regions across the rangelands.

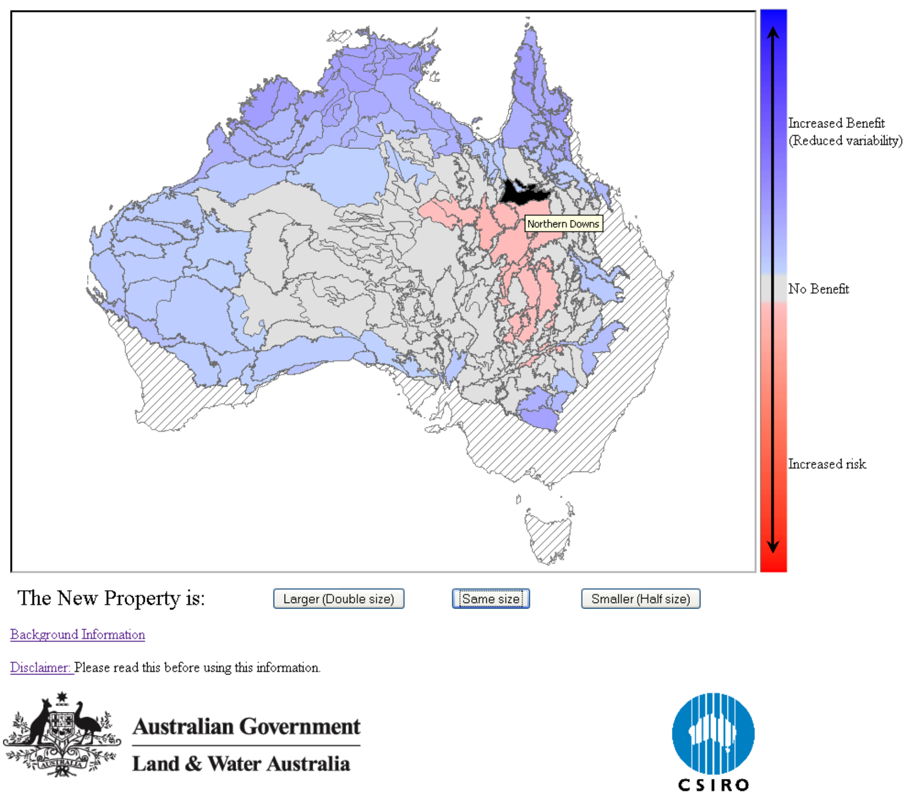
The property network analysis started by simply plotting graphs of the time series of year-to-year variation in plant growth across the set of properties in an enterprise to show the coincidence of drought across properties and to show how much these patterns of variation offset each other to reduce variation in combined plant production across the full enterprise. These were then provided to participants, together with a case study showing poor diversification and a contrasting case study showing good diversification for comparison. These analyses helped to identify the exposure of the enterprise to the risks of climate variability and which properties were contributing least to geographic diversification of these risks.

Comparison of case studies with good and poor geographic diversification of climate risk.



The second approach mapped potential opportunities for geographically diversifying climate risk at both property and regional scales. At the property scale, the CVB was calculated between the existing property holding in each case study and every other pastoral property in Queensland. For a broader national view of where opportunities could exist, the CVB was calculated between the existing property holding and every IBRA subregion within the rangelands. This approach was further developed into an interactive HTML tool that provides a way to explore the CVB relationships between any pairing of IBRA subregions in the rangelands.

Screenshot of the interactive HTML tool developed to explore patterns of the coefficient of variation benefit (CVB) scores between IBRA subregions.



Objective 3. Together with land mangers, raise awareness of the practical benefits of vegetation diversity and options for maintaining this resource.

In the final visit with participants at the end of the project, the analogy was drawn between the benefits of regional-scale vegetation diversity and within-paddock vegetation diversity. Just as having all properties in one vegetation type puts ‘all your eggs in one basket’ in terms of exposure to climate variability, so does having paddocks with only one land type and one forage species (e.g. monocultures of Indian couch or buffel grass). Diverse species and diverse mixes of land types within paddocks provide a set of forage sources that respond differently to intra-seasonal and inter-annual climate variation, providing greater diet choice for livestock and allowing cattle to better maintain diet quality (particularly through the dry season).

An earlier project demonstrated this effect using faecal NIRS analysis of dung samples from paddocks differing in vegetation diversity. Some of the participants in the current project had also participated in the previous one. The results of the earlier study were provided to project participants in a newsletter (Appendix Fig. 1). One of the key threats to vegetation diversity in rangelands comes from the risks associated with inappropriate management responses and overgrazing during drought periods. The information provided to participants helped to highlight which enterprises confronted the greatest challenges from variability in forage supplies. Geographic diversification represents one approach for reducing exposure to these risks. Participants also provided a number of alternative options that they would use to respond to periods of reduced forage availability to avoid overgrazing and damaging vegetation resources. These options included diversification of on-property activities (e.g. farm stay camps and tourism), buying into an off-farm business, investing into property and equities to provide a supplementary source of revenue, and destocking and taking off-farm employment during severe droughts. All of these options provide another source of income that can alleviate financial pressures during drought and provide the flexibility to maintain long-term management strategies, rather than being pressured into damaging, short-term crisis management.

Knowledge and adoption activities

Knowledge and adoption activities took the form of engaging with a group of 14 pastoralists who were recruited to participate in the study to provide a set of case studies for evaluating the proposed analyses. Eleven participants were from family-operated enterprises that already managed multiple properties, one had a single property but was looking to expand in the future, and two participants were large pastoral companies.

At the start of the project, the project team visited and interviewed each participant, following a questionnaire to provide background context on the rationale behind their property purchasing (and selling) decisions, and what synergies they aimed to achieve by combining multiple properties within their business. Participants were given background on the proposed approach of the project to assess the benefits of geographic diversification. This background information and feedback was used to refine the analytical approach and design ways of providing information to assist in their decision making. Participant interviews provided useful additional information on the rationale behind property purchasing decisions, the priorities in the benefits managers aim to achieve by linking networks of properties together, and the context within which the information and tools we have developed could be used. Participants were given a newsletter with project information during the project (Appendix) and were visited again at the end of the project to discuss case study results, respond to a questionnaire and provide feedback.

Given the innovative nature this project, the approach of intensive interaction with a few participants proved to be more useful than a broader group-based approach that would have reached more people but would have made it more difficult to engage effectively in conveying the project concepts. Despite the fact that some participants were initially fairly sceptical about the basis for the project, their feedback has been quite positive once they have seen the results of case studies applied to their own enterprises. It is clear from these interactions that the involvement of some participants in the project has caused them to think more carefully about: a) their strategic objectives in purchasing multiple properties (beyond the specific aims of this project), b) how exposed their enterprise is to the risks of climate variability, and c) what strategies they can put in place to deal with the inevitable risks of drought.

Future potential

The methods we have developed in this project could be extended to have widespread application in the conservation and management of natural resources. For example, an identical approach could be used to diversify climate risk in rain-fed cropping industries (at both enterprise and national scales). Similar approaches could be applied to the design of conservation reserve systems, particularly in diversifying the risks for linked meta-populations of target animal and plant species. In the management of pests or diseases, maps like the ones we have provided could highlight potential areas of reservoir populations where pests are able to take refuge during critical parts of their life cycle where they are otherwise being controlled in agricultural landscapes. What this project demonstrates is that it is not just the amount of resources (e.g. rainfall or plant growth) available in a particular part of the landscape that is important, but also the timing of when those resources are available relative to surrounding areas. A portion of the landscape that may have relatively poor resource yield may be functionally very important if it provides those resources at times when resources in other parts of the landscape are scarce. Quantifying these patterns opens up numerous opportunities for improving the management of natural resources, particularly with regard to mitigating the risks associated with climate variability.

Full Report

Introduction

It is well recognised how climatic variability leads to high variability in forage resources between years in Australian rangelands (McKeon *et al*. 2004). This has implications for landscape health and economic viability. There is a history of major degradation events in Australian rangelands as a consequence of inappropriate management responses to runs of drought years (McKeon *et al*. 2004). However, little attention has been paid to the opportunities for using spatial variability in vegetation productivity and quality as a means of coping with climate variability and avoiding degradation problems.

Vegetation diversity and local climate influences combine to produce differences between regions in the patterns of plant growth from year to year, such that the timing of favourable and unfavourable pasture growth years can vary between regions. Over the past century, the spatial heterogeneity of resources available to livestock and land managers has been reduced by subdivision of rangelands into separated enterprises, and by intensification within properties (Stokes *et al*. 2004; McAllister *et al*. 2005b; Stokes *et al*. 2008). This trend is now reversing through property consolidation and increased use of agistment. Decisions on the selection of additional pastoral properties (either for purchase or strategic agistment partnerships) are currently made in isolation of how spatial heterogeneity could be used to better manage and buffer temporal variability. However, an opportunity is being missed. It should be possible to reduce the exposure of pastoral enterprises to the risks associated with climate variability by pairing together properties where drought and favourable seasons occur in different years. This could provide several benefits:

1) It could reduce the overall year-to-year variation in forage availability (and cash-flow and income) for the combined enterprise (somewhat like a diversified stock portfolio);

2) If properties are close enough together, stock could be moved from a property where forage is in short supply (and risks of over-grazing damage are high) to properties experiencing a more favourable growth season (using properties within the same enterprise or through strategic agistment arrangements between properties with separate management);

3) Where properties are further apart, stock could still be ‘moved’ between properties by selling stock on the drought-affected property and buying stock on the property where the season is more favourable for forage growth;

4) Droughts across the set of properties in the enterprise would be easier to manage because they would be less likely to occur simultaneously; and

5) Managers could be in a better position to strategically prepare for and manage climate variability to avoid land degradation during drought a) because a source of income from a property not in drought would alleviate the economic pressure to overgraze another property that was in drought and b) because managers could become more exposed to dealing with drought as a routine part of the business (since one or other property would frequently and sequentially be experiencing an unfavourable season, rather than all the properties in the enterprise simultaneously cycling together through longer-term ‘boom and bust’ periods).

While these principles of diversifying risk spatially to offset climate variability have long been recognised (Stokes *et al*. 2004; McAllister *et al*. 2005a; Stafford Smith and McAllister 2008), the challenge has been to quantify this information in a form that can be used to inform management decisions. Addressing this challenge was the main rationale and goal of this project. As the pastoral industry is going through a phase of property consolidation (after a previous history where policies have led to the subdivision and fragmentation of properties) (Stokes *et al*. 2004; Stokes *et al*. 2008) this seems like an opportune time to consider the full range of synergistic benefits that can be provided by taking advantage of complementarities between properties.

The main basis of our approach was to identify groupings of pastoral properties where fluctuating patterns of plant growth and the timing of droughts are as different as possible. In conjunction with land managers we developed and demonstrated analytical tools to assist pastoralists in deciding how groups of properties might be best located geographically to help minimise the impacts of climate variability and avoid some of the current problems associated with degradation of native vegetation condition during drought. The broad aim of the project was to provide land managers with information that will encourage them to further value, protect and utilise vegetation diversity by demonstrating the practical benefits that can be derived from this natural asset in Australian rangelands.

Research approach and methods

The overall research approach was to engage with a group of participating pastoralists with multiple-property enterprises to develop and evaluate analyses and information tools that could assist them to: 1) explore the exposure of their enterprises to the risks of climate variability, 2) evaluate how well their existing holding of properties diversified these risks, and 3) identify potential opportunities where new properties could be bought (and existing properties sold) to enhance the benefits of geographic diversification.

The first methodological challenge was to develop an approach to quantify the benefit of grouping together properties with complementary patterns of year-to-year variation in plant growth. While correlation between time series seemed like an obvious first choice (with low correlations being preferable to synchronous variation in plant production), this approach was prone to artefacts. (For example, unvegetated areas (or some deserts) consistently produce low/no plant growth every year and would thus have a very low correlation with plant growth from other rangeland areas, even where there would be no practical benefit). We therefore defined the benefit that we wanted to quantify in terms of the principle of trying to group properties together in such a way that year-to-year variation in plant growth as a proportion of the average total annual plant growth across the combined properties was as low as possible (i.e., minimising the temporal co-efficient of variation, or risk, for the combined group of properties). Based on this principle we identified two measures for quantifying complementary patterns of year-to-year variation in plant production.

The first metric measured how an existing property or group of properties in an enterprise (j) would benefit by adding another property (k) to that enterprise:

$$CVB(j,k) = CV_j - CV_{j+k}$$

where:

CVB = Coefficient of variation benefit

CV_j = coefficient of variation for the time series (year-to-year variation) of total annual plant growth for starting property, j

CV_{j+k} = coefficient of variation of the time series for the combined total plant production from properties j and k coeffienct of variation (CV) = standard deviation of time series / mean of time series

'property' j (or k) can, more generally, be an individual property, a group of properties within the same enterprise or a geographic region.

If CVB is 0, then adding the new property (k) to the existing holding (j) will not affect the overall variability to which the enterprise is exposed. If CVB is positive, then there will be a benefit in reducing year-to-year variation in plant growth for the new combined enterprise. If CVB is negative, then the new combined enterprise would be exposed to greater risk (more extreme year-to-year variation in plant growth). Note that the benefit derived by adding property k to j [CVB(j,k)] is not the same as the reverse benefit that property j adds to property k [CVB(k,j)].

The second metric measured the benefit within a group of properties, relative to the variation that individual properties would be exposed to if treated as separate entities:

WVB = ((SE(j) + SE(k)) – SE(j+k)) / (Average(j,k))

where:

WVB = Within-group variance benefit

SE(j) = standard deviation for the time series (year-to-year variation) of total annual plant growth for starting property, j

SE(j+k) = standard deviation for the time series (year-to-year variation) of combined total annual plant growth for starting property, j

Average (j,k) = average total annual plant production for the two properties.

More generally, for a group of more than two properties, WVB is given by the sum of SEs minus the SE of the sum, and this term is then standardised by dividing by the average annual plant production for the group of properties. If year-to-year variation across all properties within the group is perfectly correlated, then WVB will be 0. As patterns of production become less synchronous and start to complement each other in buffering combined temporal variation, WVB becomes larger.

The second major methodological issue was deciding on appropriate data sets to capture combined spatial (property-to-property and region-to-region) and temporal (year-to-year) patterns of variation in plant growth. The two main sources of data were: a) data derived from time sequences of satellite imagery and b) data derived from weather station records. Each had different strengths and weaknesses (Table 1). The best satellite-based data we could obtain was a time series of global net primary production (NPP) estimates based on NOAA/NASA AVHRR data which had been analysed with the GLObal Production Efficiency Model (GLO-PEM) (Prince and Goward 1995). This provided data at 8 km x 8 km resolution at monthly intervals over the period 1980–2001. The best weather-based data we could obtain were AussieGRASS estimates of forage production, which use a grass growth model (GRASP, McKeon *et al*. 1982) and spatially-interpolated weather station data. These provided estimates of forage growth over the past 120 years across Australian rangelands at monthly intervals. For both sets of data, monthly data were combined into an annual total using a 'growth year' of June–May (splitting the year around the period of minimum plant production). Some post-processing of data was done before analysis to eliminate sources of year-to-year fluctuations other than natural plant growth-climate interactions. For the satellite-based data, the data were spatially filtered to include only spatial points that were consistently used as rangelands with the same management by filtering on land use (e.g. eliminating cropping and urban areas) and land use change (e.g. eliminating areas where tree clearing had occurred). For both data sets, linear trends in time series were removed from the data. For property-scale analyses, a 10-km buffer was added around each property boundary to ensure that more than one spatial data point was used when calculating time series of the average plant growth on each property for each year (for all properties across Queensland and other properties of project participants). For regional scale comparisons, rangeland areas were divided according to Interim Biogeographic Regionalisation of Australia (IBRA) subregions (Thackway and Cresswell 1995) before calculating time series of the average plant growth for each region for each year.

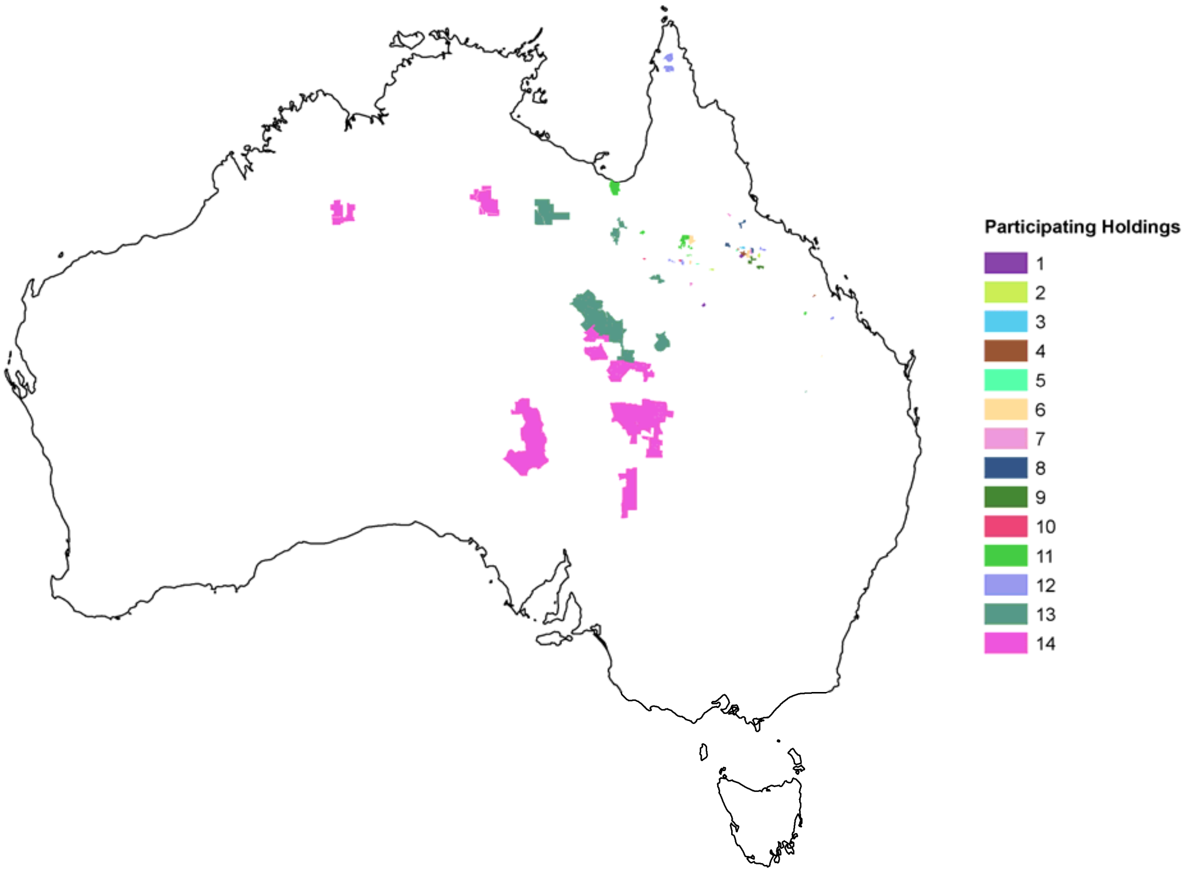
Table 1: Comparison of spatial time series sources of data for plant growth

Advantages	Disadvantages
a) GLO-PEM data (satellite-based)	
Captures high resolution patterns of variation in plant growth (sufficient for property-scale comparison)	The data only covered 20 years of patterns of variability in plant growth
	Plant growth measures include tree growth
	In very arid areas with sparse vegetation, accurate measures of year-to-year variation are masked by a strong background signal of bare ground
	Measurements include the effects of land use, land use change and management
	Measurements not calibrated for Australian rangelands
b) AussieGRASS data (modelled from spatially-interpolated weather data)	
The data captures 120 years of patterns of variability in plant growth	Weather stations are sparsely distributed so interpolated weather data only captures regional scale (not property scale) patterns of climate variability
The data provides measures of grass (forage) growth alone	Weather stations are particularly sparse in the desert regions (so interpolated data is even less reliable)
Calibrated for Australian rangelands (and provides a better indicator of fluctuations in pasture growth than rainfall data)	

For property-scale analyses we judged the satellite-based data to be preferable, because the data was at sufficient spatial resolution to capture the differences in year-to-year patterns of variation at this fine scale. For regional-scale analyses we found it preferable to take advantage of the longer-term patterns of variability captured by the data derived from historical weather records. To handle the very substantial amounts of data and processing involved, all analyses were implemented within a database using search and query language (SQL).

A group of 14 pastoralists were recruited to participate in the study to provide a set of case studies for evaluating the proposed analyses (Fig. 1). Eleven participants were from family-operated enterprises that already managed multiple properties, one had a single property but was looking to expand in the future, and two participants were large pastoral companies. At the start of the project, the project team visited and interviewed each participant, following a questionnaire to provide background context on the rationale behind their property purchasing (and selling) decisions, and what synergies they aimed to achieve by combining multiple properties within their business. Participants were given background on the proposed approach of the project to assess the benefits of geographic diversification. This background information and feedback was used to refine the analytical approach and design ways of providing information to assist in their decision making.

Figure 1. Property holdings from the 14 pastoral enterprises that participated and were used for case studies in this project.



Several approaches and tools were developed to visualise the output from analyses to help property managers identify vulnerabilities to climate variability and potential options and opportunities to reduce these risks. These were: a) an analysis of the existing property network, b) maps of properties and regions with complementary patterns of year-to-year variation in plant growth (using our CVB scores), and c) a web-based interactive HTML tool that can be used to explore complementarities (CVB) between any pair of regions across the rangelands.

The property network analysis started by simply plotting graphs of the time series of year-to-year variation in plant growth across the set properties to show the coincidence of drought across properties and to the extent to which these patterns of variation offset each other to reduce variation in combined plant production across the full enterprise. These graphs were given to participants together with a case study showing poor diversification and a contrasting case study showing good diversification (from a family-run enterprise, rather than one of the large pastoral companies) for comparison. The network of properties in each enterprise was further analysed by dropping properties one at a time and calculating the within-group variance benefit (WVB) for the remaining properties and the coefficient of variation benefit (CVB) between that property and the other properties in the enterprise. These analyses helped to identify the exposure of the enterprise to the risks of climate variability and to show which properties were contributing the least to geographic diversification of these risks.

The second approach mapped potential opportunities for geographically diversifying climate risk at both property and regional scales. At the property scale, the CVB was calculated between the existing property holding in each case study and every other pastoral property in Queensland. Maps were then provided showing this data for a region where each participant had indicated they would be interested in purchasing new properties. For a broader national view of where opportunities could exist, the CVB was calculated between the existing property holding and every IBRA subregion within the rangelands.

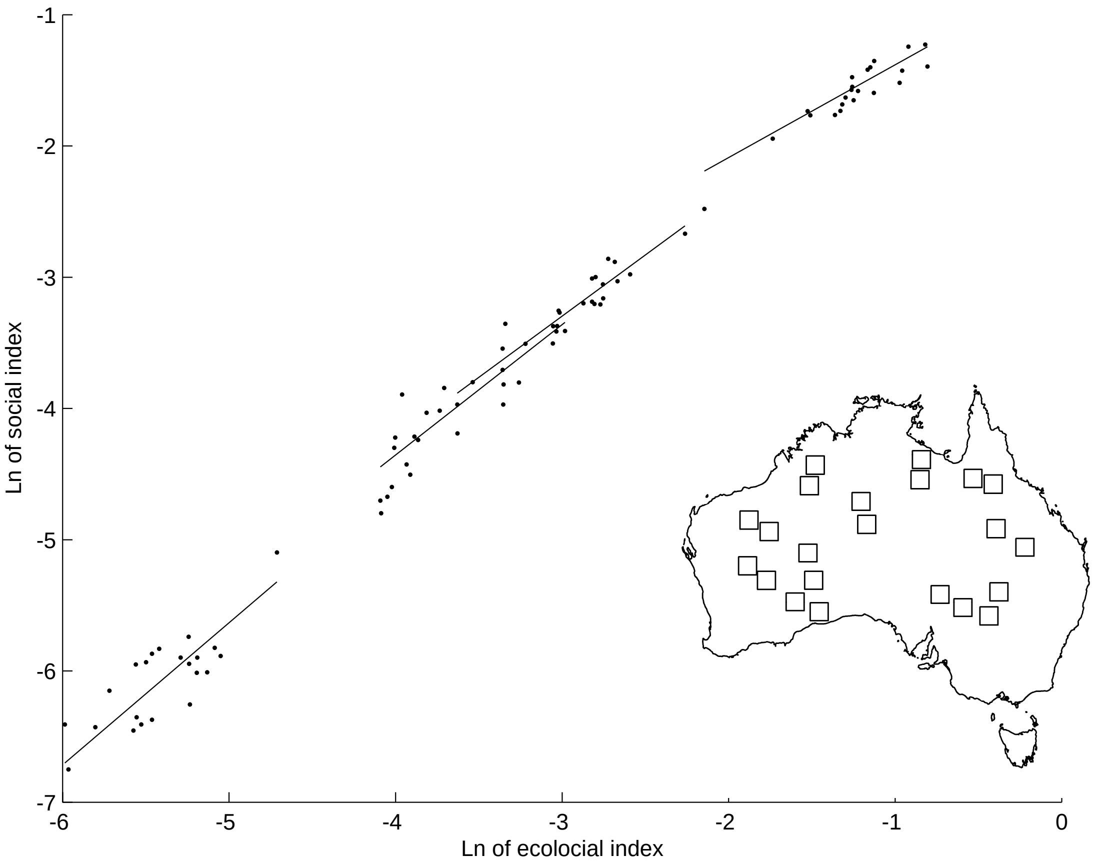
The last visualisation tool provided a more general way of exploring opportunities for geographic diversification across the rangelands. The case studies provided tailored analyses for each participant based on their specific set of properties. For more general use, we calculated CVBs for every pairing of IBRA subregions across the rangelands. This data was then used to generate a map for each IBRA subregion showing its CVB relative to every other CVB. These were combined into an interactive HTML tool that allows easy exploration of patterns and opportunities, both for pastoralists and other potential users, such as conservation planners.

Each participant was then visited again at the end of the project to present the results of the case studies and to obtain feedback and answers during a final interview.

Project findings

After refining our analytical methods and metrics of benefit, the first data analysis we conducted was to validate the metric. We did this by calculating our proposed within-group variance benefit (WVB) scores for 22 locations in Australian rangelands using the satellite-derived vegetation production data. We then used an agent-based model running on the same data to derive an independent measure of how pastoralists could benefit from exploiting spatio-temporal variation (based on trading surplus forage in agistment networks: McAllister *et al*. 2006). The strong correlations between our purely biophysical metric and an independent measure of socio-economic benefit confirmed that our measure of biophysical potential was a good indicator of practical realisable benefits in coping with climate variation and drought (Fig. 2).

Figure 2. Testing of an ecological index of complementarity in patterns of resource fluctuations (x axis: based on reduced exposure to the risks of year-to-year variation in plant production) shows that the metric achieves its objective of indicating practical, achievable benefits for pastoralists and other consumers (y axis: based on improvements in resource use from agent-based models of pastoralists in agistment networks). Inset map shows selected rangeland regions from which input time series of plant production data were sampled.

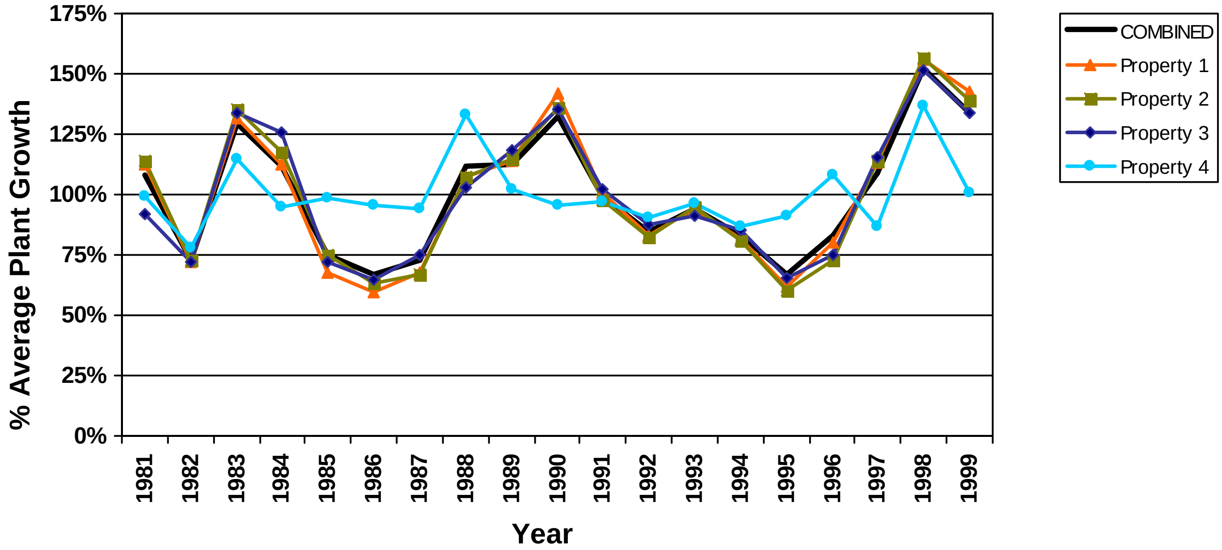


Figures 3–5 show an example of a set of case study analyses. A set of 14 such case study analyses were generated for project participants. The analysis of the existing network of properties within each enterprise (Fig. 3) showed how well the patterns of variation in plant production complemented each other in terms of buffering and smoothing out variability for the combined enterprise as a whole.

In the case of poor geographical diversification, the risks of climate variability are compounded by ‘having all your eggs in one basket’, and the enterprise as a whole is subject to no less risk than each of the properties individually (Fig. 3). The case study with good diversification is like having a diversified stock portfolio, and buffers risk such that the year-to-year variation for the combined enterprise is much lower than that for the individual properties. Aside from having the potential to even out the revenue stream for the combined enterprise, geographic diversification also has potential to improve management responses to drought. Firstly, in the case of good diversification, the incidence of drought is spread across properties so that only a few properties are in drought at a time, rather than going through synchronous boom and bust cycles. This means that while one property is in drought, others in the enterprise often will not be, alleviating the pressure to deal with one localised problem at a time. Where properties are close enough together, livestock could be moved between properties. Where properties are further apart, there would still be benefit, since the income and cash flow from other properties would assist in maintaining long-term management strategies and reducing stock numbers on the drought-affected property. It would still be possible to ‘move’ cattle large distances by selling stock on drought-affected properties and buying extra cattle on other properties where favourable seasons may provide surplus forage. In addition, the boom and bust cycles of poor diversification can give rise to the ‘hydro-illogical’ cycle where prolonged periods of favourable seasons can lead to a build up of stock numbers and reversion to riskier management practices, based on the expectation that favourable seasons are ‘normal’ and will continue. This leaves the enterprise poorly prepared when all properties simultaneously next go into drought. In contrast, in the diversified case, the occurrence of drought on one or other property occurs frequently and dealing with these situations (sequentially, rather than as a simultaneous crisis) becomes part of normal management practice and expectation. This simple illustration of participants’ exposure to the risks of climate variability on their own enterprises proved to be quite informative, and in some cases there was less geographic diversification than had been assumed to be the case.

In response to any vulnerabilities that became apparent from the property network analysis, one option would be to look at reconfiguring the network of properties over time to improve geographical diversification of climate risks. Maps of the coefficient of variation benefit (CVB) scores between the case study property holdings and a) other pastoral properties (Fig. 4) and b) IBRA subregions in rangeland (Fig. 5) provided information to help guide these decisions. A more generalized interactive HTML tool was also developed that would allow patterns of coefficient of variation benefit (CVB) scores to be explored between any pair of IBRA subregions within the rangelands (without the need to run a customised case study analysis). There are several important caveats in using and interpreting these analyses. In addition to the issues raised with the sets of data (Table 1), the patterns of climate variation analysed are for historic data and may not be the same over the long term in the future. Moreover, such broad-scale analyses cannot replace detailed local knowledge. It is therefore recommended that these analyses be used as a ‘prospecting tool’ to identify potential candidate regions for more detailed local investigation. Importantly, these analyses capture only one specific aspect of the beneficial synergy between properties. It is also useful to consider how forage productivity varies between regions (Fig. 6) and how variable this production is from year-to-year (Fig. 7) before this variation is mitigated by geographic diversification.

Numerous other (more important) considerations go into deciding on the value of a property and whether it fits into an overall enterprise strategy. But, while these other considerations are a routine part of decision making, it has been difficult to make strategic decisions about geographical diversification of climate risk in the past, because the tools have not been available (and conventional wisdom on where such complementarities may exist has not always been borne out by the network analyses in the case studies).



Network Analysis Summary

Property	CV	CVB Total	CVB per Ha	WVB	
Whole enterprise	25.2%			0.5%	
Property 1	29.3%	-3.8%	-3.4%	1.5%	Property adds risk
Property 2	29.0%	-0.9%	-2.3%	0.8%	
Property 3	27.1%	-0.1%	-0.8%	0.6%	
Property 4	14.6%	3.6%	10.9%	-0.6%	Property reduces risk

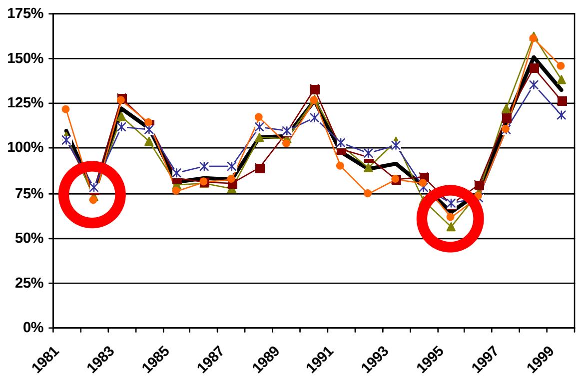
CV = temporal coefficient of variation in plant production
CVB = Coefficient of Varition Benefit for property relative to the group of other properties in the enterprise
WVB = Within-group Variance Benefit for the remaining properties if the selected property is removed

Poor Diversification

High risk – “all your eggs in one basket”
Droughts hit all properties in the same years
Exaggerates bad years for overall business

Good Diversification

Reduced risk – “broad stock portfolio”
Droughts hit properties in different years
Smooths income stream of overall business



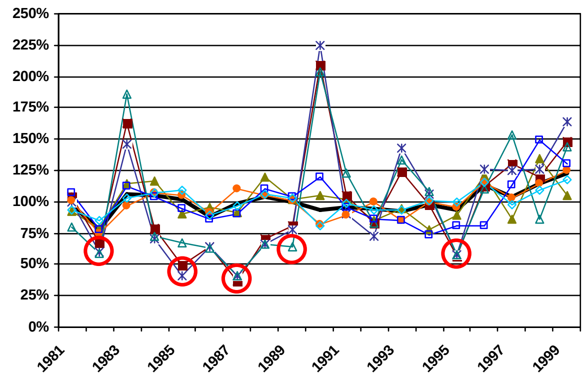


Figure 3. Example from a network analysis of one of the case study enterprises

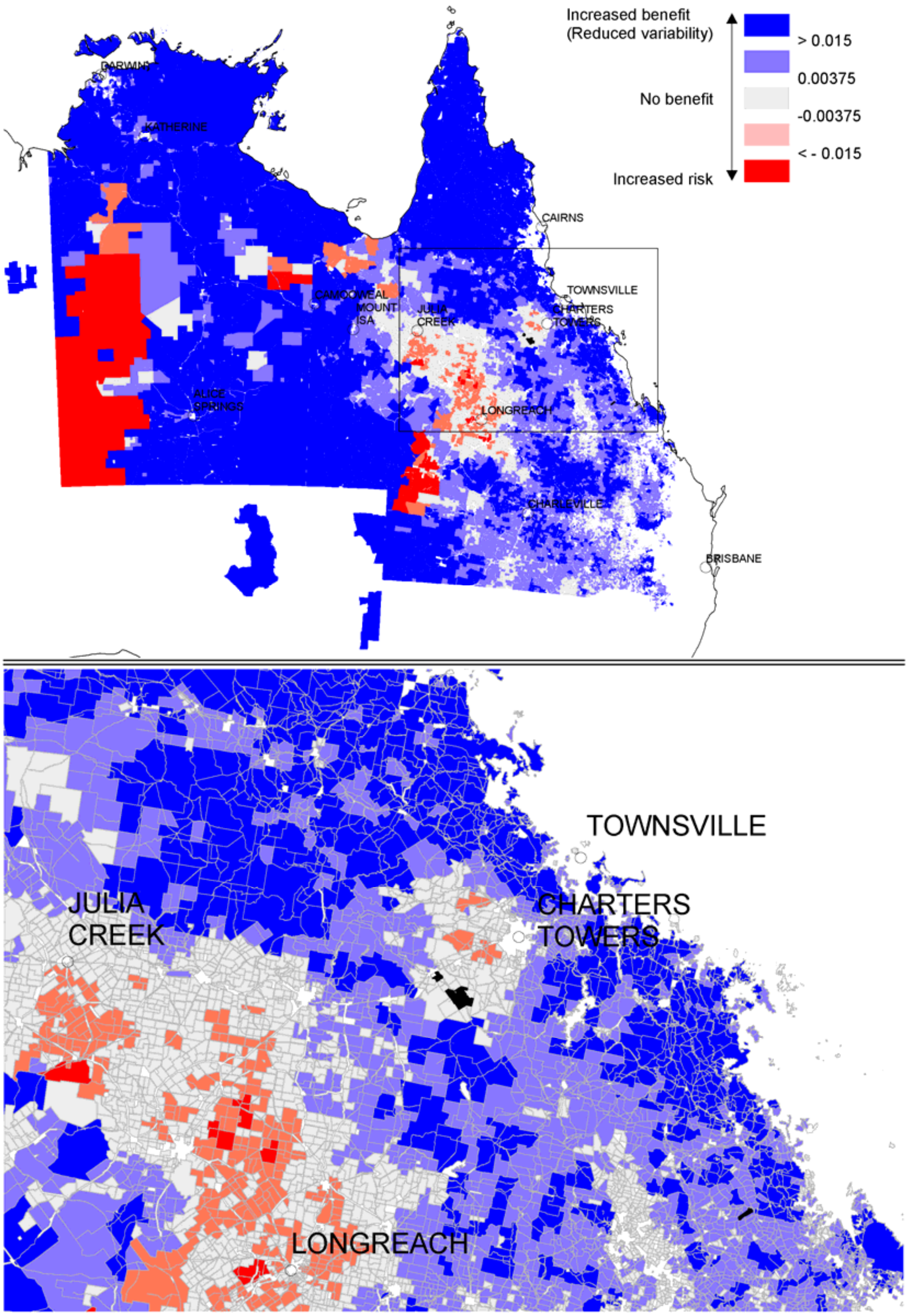


Figure 4. Example of the mapped results from a case study enterprise showing property-scale measures of the coefficient of variation benefit (CVB) scores between the enterprise and other pastoral properties.

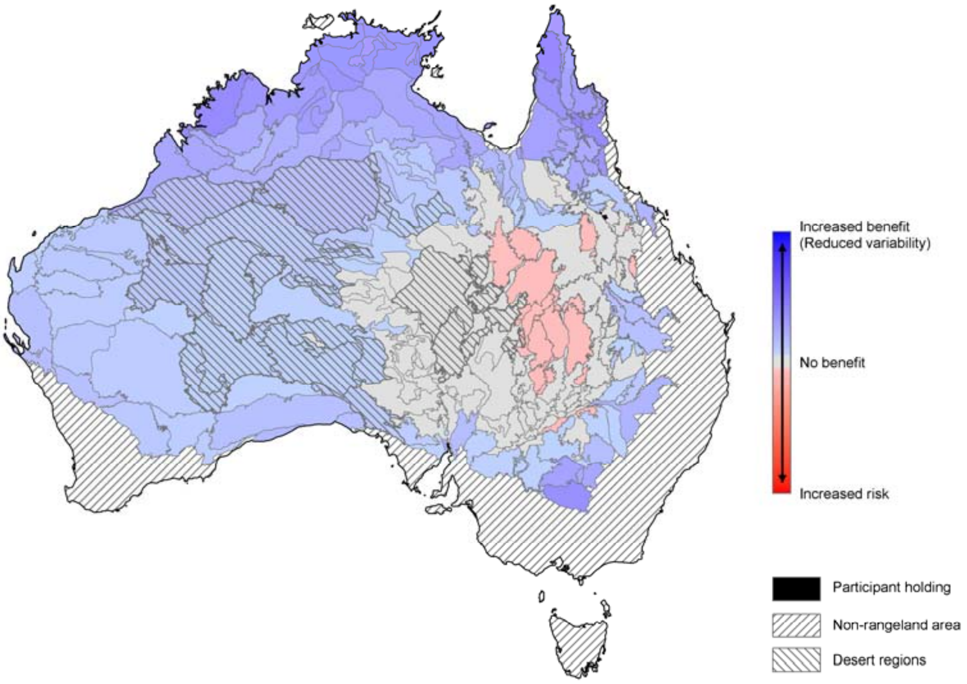


Figure 5. Example of the mapped results from a case study enterprise showing the coefficient of variation benefit (CVB) scores between the enterprise and IBRA subregions across the rangelands.

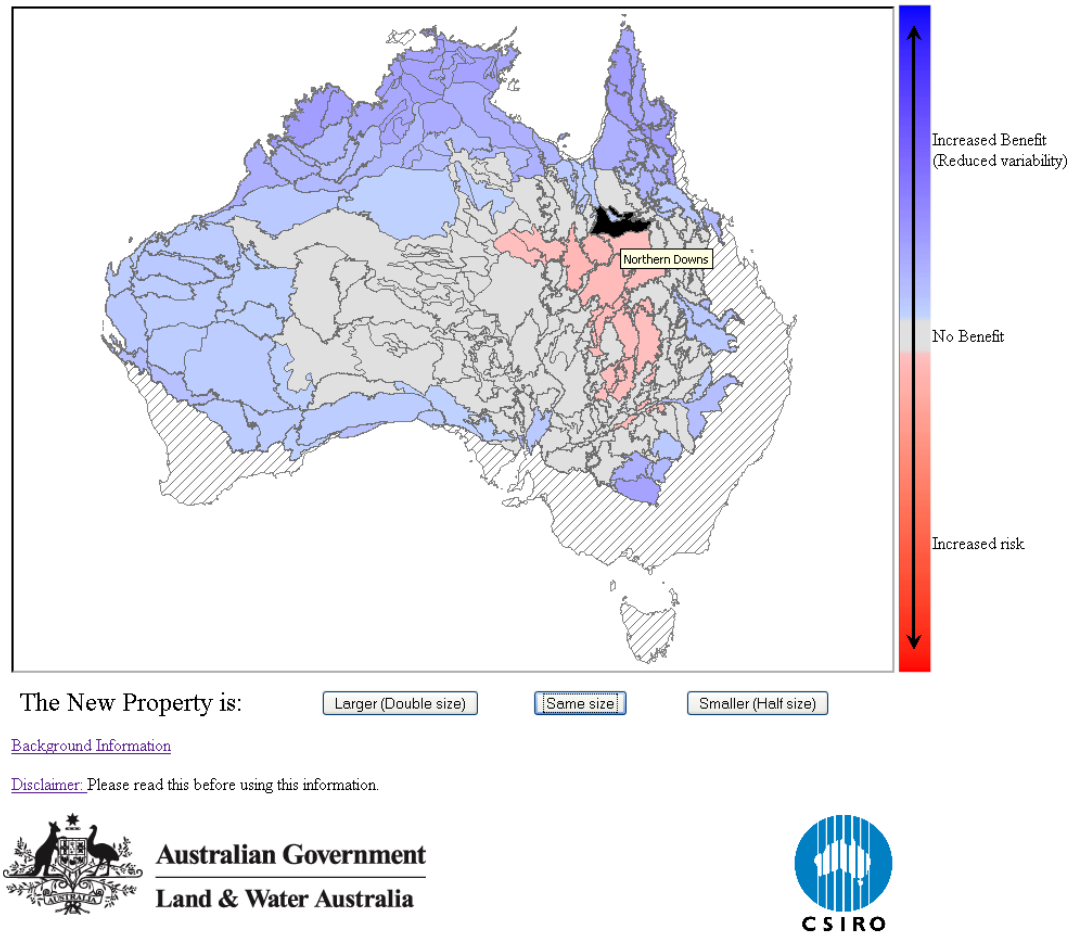


Figure 6. Screenshot of the interactive HTML tool developed to explore patterns of the coefficient of variation benefit (CVB) scores between IBRA subregions.

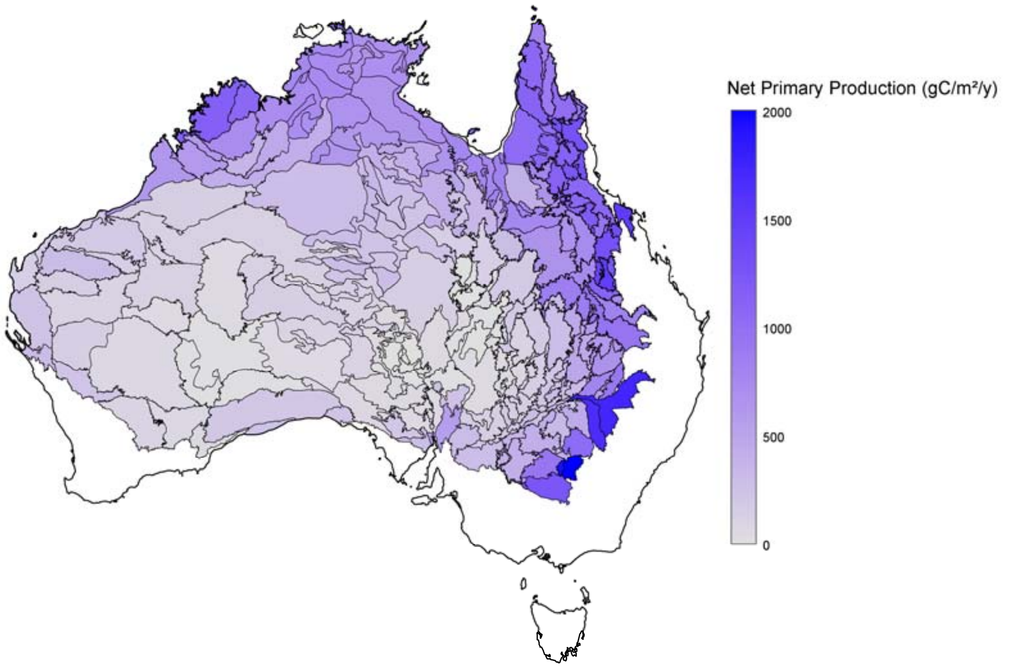


Figure 7. Average measures of grass production from a 120-year time series of AussieGRASS data for each IBRA subregion.

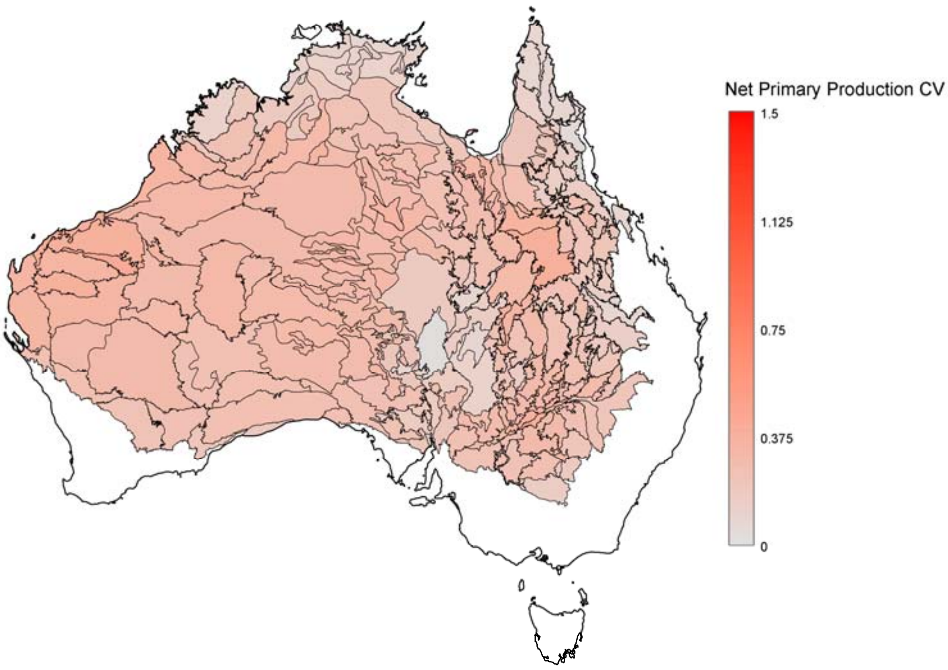


Figure 8. Coefficients of variation (CV) for a 120-year time series of AussieGRASS grass production data for each IBRA subregion.

Knowledge and adoption

Interviews and feedback from participating pastoralists provided useful additional information on the rationale behind property purchasing decisions, the benefits in order of priority that managers hope to achieve by linking networks of properties together, and the context within which the information and tools we have developed would be used.

The most important reasons given for wanting to expand pastoral enterprises were to gain economies of scale (to increase profitability, rather than having to expand a sub-economic enterprise), opportunistic buying (often with the perception that opportunities for obtaining good properties at a reasonable price were declining), and intergenerational planning (to provide opportunities for more than one child to continue in the pastoral business). Many pastoralists recognised that there were numerous potential synergistic benefits in the way that differences between properties complement and 'fit' each other. But often these complementarities were realised more with the benefit of hindsight than through strategic forward planning, or could not be achieved because property selections have been constrained by what land has been available for sale at the times of expansion. Of these complementarities, those that featured most strongly in forward planning were creating a mix of country types (e.g. breeding and fattening properties), access to markets (e.g. so that the flow of animals from breeding, to fattening, to finishing properties moved cattle towards feedlots and sale yards) and diversifying climate risk. Several constraints were also identified as limiting the potential to benefit from geographic diversification by restricting the choice of properties to confined geographic areas. These included a preference for purchasing properties in one country type (with which managers were familiar) and preferring properties that were in close proximity to the 'home' property (especially where properties were run by a group of family members or where there was a reluctance to employ property managers). There are obviously additional cost and finance issues associated with purchasing and operating widely-spaced properties. However, most participants indicated they would be prepared to consider purchasing properties more than 500 km away from their home base if it would meet their objectives.

In the final visit with participants at the end of the project, the analogy was drawn between the benefits of regional scale vegetation diversity and within-paddock vegetation diversity. Just as having all properties in one vegetation type puts 'all your eggs in one basket' in terms of exposure to climate variability (Fig. 3), so does having paddocks with only one land type and one forage species (e.g. monocultures of Indian couch or buffel grass). Diverse species and diverse mixes of land types within paddocks provide a set of forage sources that respond differently to intra-seasonal and inter-annual climate variation, providing greater diet choice for livestock and allowing cattle to better maintain diet quality (particularly through the dry season).

An earlier project demonstrated this effect using faecal NIRS analysis (which measures diet qualtiy) of dung samples from paddocks differing in vegetation diversity. Some of the participants in the current project had also participated in the previous project, and the results of that study were provided to current project participants in a newsletter during the project (Appendix Fig. 1). One of the key threats to vegetation diversity in rangelands comes from the risks associated with inappropriate management responses and overgrazing during drought periods. The information provided to participants helped to highlight which enterprises confronted the greatest challenges from variability in forage supplies. Geographic diversification represents one approach for reducing exposure to these risks. Participants also provided a number of alternative options that they would use to respond to periods of reduced forage availability to avoid overgrazing and damaging vegetation resources. These options included diversification of on-property activities (e.g. farm stay camps and tourism), buying into an off-farm business, investing into property and equities to provide a supplementary revenue stream, and destocking and taking off-farm employment during a drought. All of these options provide an alternative source of income that can alleviate financial pressures during drought and provide the flexibility to maintain long-term management strategies, rather than being pressured into damaging, short-term crisis management.

Future potential

The methods we have developed in this project could be extended to have widespread application in the conservation and management of natural resources. For example, an identical approach could be used to diversity climate risk in rain-fed cropping industries (at both enterprise and national scales). Similar approaches could be applied to the design of conservation reserve systems, particularly in diversifying the risks for linked meta-populations of target animal and plant species. In the management of pests or diseases, maps like the ones we have provided could highlight potential areas of reservoir populations where pests are able to take refuge during critical parts of the life cycle where they are otherwise being controlled in agricultural landscapes. This project demonstrates that it is not just the amount of resources (e.g. rainfall or plant growth) available in a particular part of the landscape that is important, but also the timing of when those resources are available relative to surrounding areas. A portion of the landscape that may have relatively poor resource yield may be functionally very important if it provides those resources at times when resources in other parts of the landscape are scarce. Quantifying these patterns opens up numerous opportunities for improving the management of natural resources, particularly with regard to mitigating the risks associated with climate variability.

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APPENDIX:

Background newsletter provided to participants after they were recruited

Dear ####LWA_Participant#####

Thank you for agreeing to participate in our project to look at some of the benefits that multi-property enterprises can achieve through strategic use of complementary differences between properties. This current project, funded by Land & Water Australia, has built on some past research we did as part of a larger international collaborative project in rangelands across the world (nine across Australia, Asia, Africa, and North America). This letter provides some information to project participants who may be interested in the overall findings of this research, as background to the work we are now doing.

The first part of this feedback is specifically on the local, northeast Queensland part of the previous project. We analysed dung samples from participating pastoralists to find out how cattle diet quality was affected by the characteristics of the paddocks cattle were grazing in. In the second part we provide a brief summary of the findings for the rest of the international project, and how this gave rise to the current project that you are now involved in.

Thank you again for your participation in this research.

Regards,

Chris Stokes & Mike Nicholas

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Dung sampling (diet quality) experiment

In this research, we wanted to find out whether seasonal variation in the diet quality of cattle was affected by the sizes of paddocks and the diversity of vegetation in them. In particular, we wanted to test whether large paddocks and paddocks with diverse mixes of vegetation would provide greater opportunities for diet selection by cattle. Would this allow cattle to better regulate their nutrition, particularly during the dry season?

Paddocks with diverse vegetation help cattle maintain a better quality diet

The main finding from the combined set of dung sampling (cattle diet quality) data was that paddocks with a more diverse mix of vegetation helped cattle to maintain a better diet quality through the dry season.

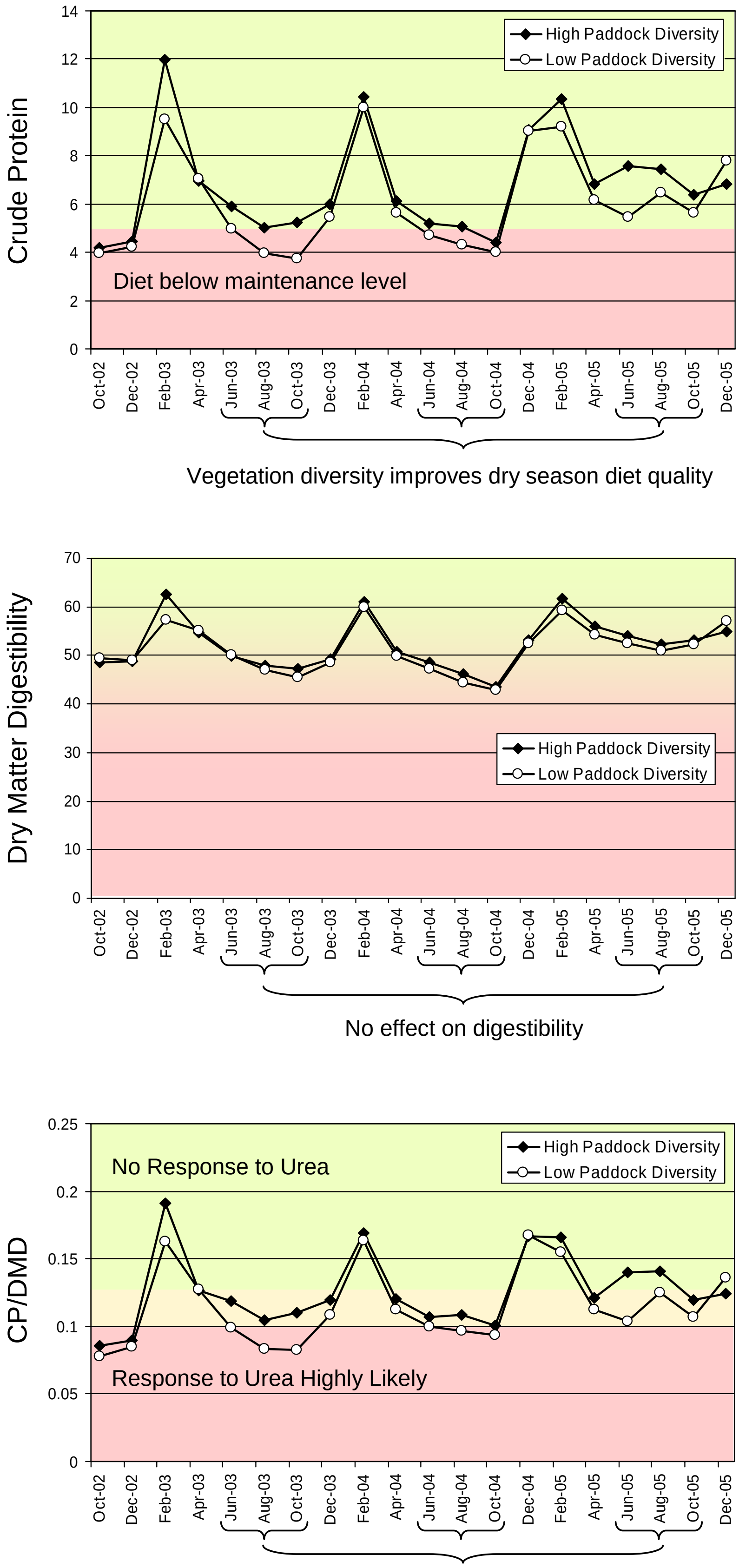
This experiment involved analysing dung samples from selected paddocks in the Dalrymple Shire to compare cattle diet quality to paddock characteristics. Paddocks were selected in collaboration with participating property managers, to ensure they were suitable for the study. The set of paddocks were selected to cover a range of sizes (from 600 to 27,000 ha) and differing degrees of vegetation diversity. Initially, in September 2002, we recruited 18 pastoralists from the shire to collect faecal samples for analysis at two-monthly intervals from a total of 35 paddocks. In December 2003 we added an additional 30 paddocks to fill in gaps in the sample design across the set of selection attributes (paddock size, geology type, landscape complexity) and to allow for the loss of some paddocks from the study (e.g., because of destocking, changes in fencing or discontinued/irregular provision of faecal samples from collaborators due to continuing drought). The study paddocks covered three different geological/land types that differed in productivity: Basalt (most productive, 18 paddocks), Igneous (16 paddocks) and Canozoic (least productive, 16 paddocks with enough returned dung samples). Dung samples were provided at two-monthly intervals until early 2006 and were analysed using near infra-red spectroscopy (NIRS) to quantify seasonal variation of diet quality in paddocks. For each dung sampling paddock we calculated a set of descriptive paddock characteristics:

- Paddock area (ha);
- Vegetation diversity (from satellite images);
- Topographic variation;
- Average distance from permanent water;
- Number of soil types in the paddock; and
- Stocking rate (number of stock grazing days ha^{-1} yr^{-1})

Faecal data was then statistically analysed to test whether each paddock characteristics influenced the diet quality of cattle, particularly during the dry season (June – October). (The difficulty in collecting and sending wet season dung samples made analysis problematic for wetter parts of the year).

Near Infrared Spectroscopy analysis of dung samples provided estimates of the dry matter digestibility (DMD) and crude protein (CP) content of cattle diets. The ratio of CP:DMD was used as a measure of how likely cattle would be to respond to urea supplements. Cattle in paddocks with **high vegetation diversity were better able to maintain their diets through the dry season** than cattle in low diversity paddocks (**Figure 1**). Neither paddock size nor any of the other paddock characteristics was found to have a significant influence on cattle diet quality.

These results show that vegetation diversity can benefit cattle nutrition. The mix of different forage types allows cattle to select a more nutritious diet. This is particularly useful in maintaining nutrition through the dry season (which could reduce the duration and amount of supplements needed).



Cattle in diverse paddocks require less urea supplements

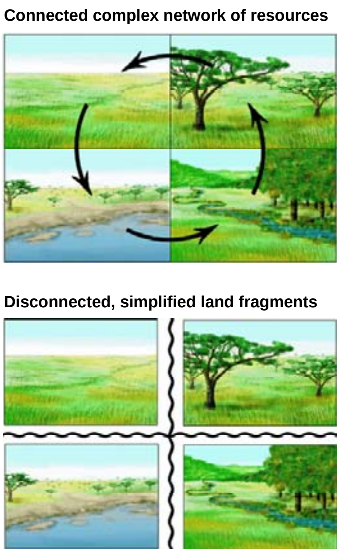
Fig 1: Comparison of seasonal variation in cattle diet quality for paddocks with high and low vegetation diversity. Cattle in paddocks with more diverse vegetation are able to maintain a better diet through the dry season (requiring less supplements).

The international SCALE project

(SCALE = Scale and Complexity in Arid Land Ecosystems)

Our work was part of an international collaboration, funded mainly from the United States, with nine study sites in rangelands around the world (northeast Queensland, Australia; Northern Great Plains, USA; Jackson Valley, Wyoming, USA; Kazakhstan; Mongolia; Athi-Kaputiei Plains, Kenya; Amboseli, southern Kajiado District, Kenya; Ngorongoro Conservation Area, Tanzania; North-West Province, South Africa). Globally, the arid and semi-arid systems that make up the world's rangelands are significant, making up almost a quarter of the earth's landscapes and supporting the livelihoods of more than 20 million people. Rangeland ecosystems are also home to several of the planet's remaining large mammals, as well as other important species. Over the past century, traditional migratory patterns of rangeland use have been increasingly disrupted, with negative consequences for rangeland resources and the linked human societies and animals that depend upon them.

We wanted to find out how changing patterns of land tenure and use are affecting the ways humans, livestock and wildlife interact with rangeland resources (such as different types of forage and water). Over millennia, human cultures and large animals have adapted to rangeland environments by moving large distances (often hundreds of kilometres) to link a complex mix of different types of resources as a means of coping with harsh and variable climates. But modern changes in land use and tenure have fragmented rangelands into smaller, simpler, isolated units. While these changes in land use have often helped governments to meet policy objectives (e.g., privatization of land tenure, settlement of nomads, intensified land use or increased control by centralized communist governments), the costs of the loss of broad scale access to spatial diversity have not been well recognized. The project work was intended to assist policy makers, particularly in developing countries, to avoid some of the past mistakes from well-intentioned (but often counterproductive) interventions to promote development in rangelands.



The project found that globally, fragmentation of rangelands is caused by a suite of factors (technological, economic, policy, institutional and demographic: **Figure 2**). These causes often originate far from rangelands and divide landscapes into parts through physical barriers such as fences and administrative barriers such as political boundaries and social norms. Fragmentation also occurs as land is converted from one land use type to another, particularly cropping and parks and reserves. The first lands to become fragmented are those in more productive rangelands, with access to key resources (e.g., river frontage or wetlands), near towns, along roads and near markets.

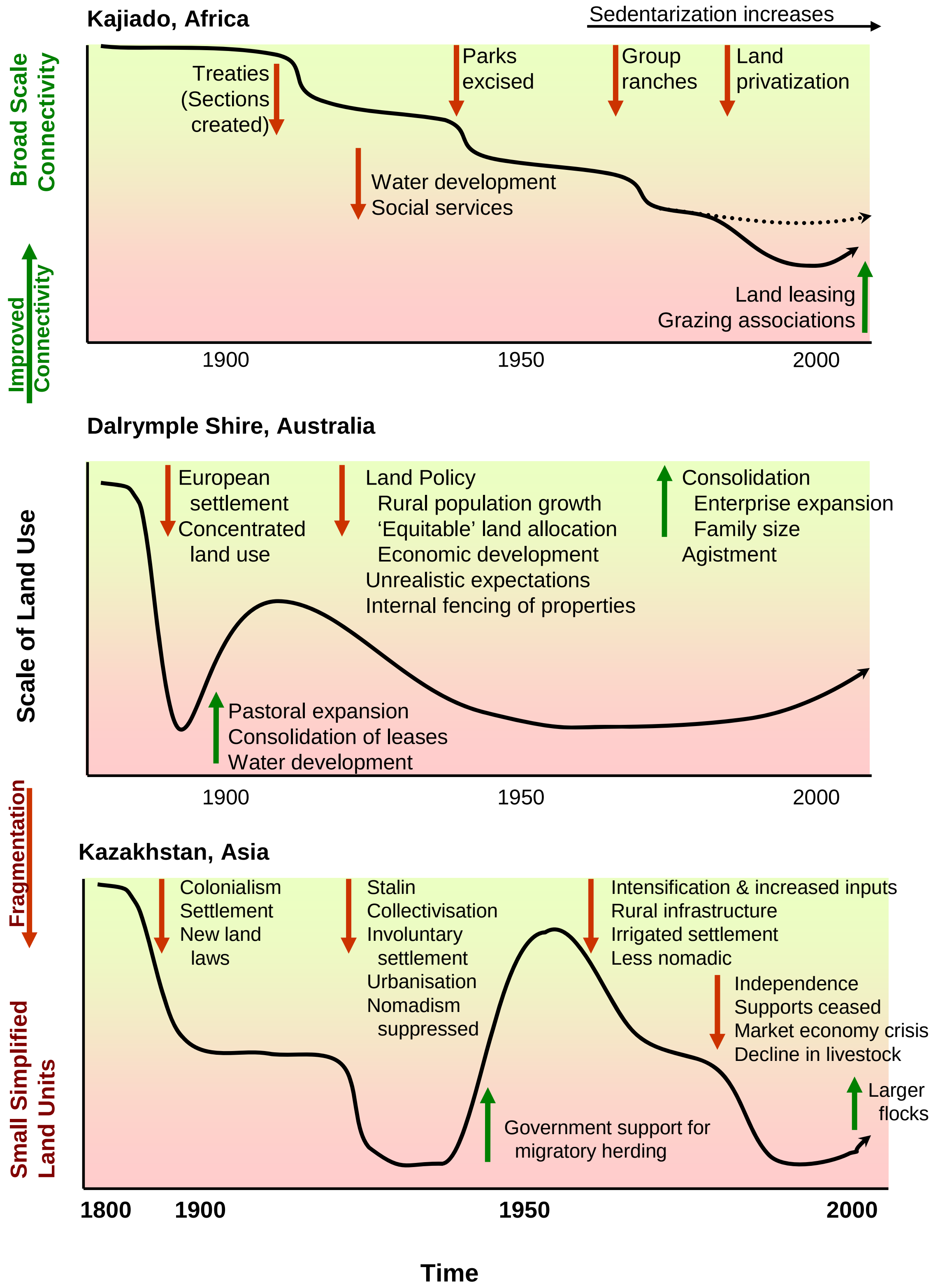


Figure 2: Historic patterns of fragmentation in three contrasting rangelands around the world. Downward arrows indicate the diverse set of drivers that have reduced the scale of land use, mobility of land users and access to rangeland diversity. Upward arrows indicate drivers that reconnect land fragments, restoring broad scale access to patchy resources.

The work in the project provided evidence of the benefits of access to broad scale resource diversity in rangelands, and of the negative impacts that rangeland fragmentation brings. For example, GPS tracking of cattle herds in east Africa showed that animals spent more time walking and less time feeding in fragmented rangelands. In addition, access to

alternative sources of forage in drought years is becoming increasingly restricted. In Kazakhstan, owners of small, sedentary flocks of sheep achieved lower financial returns per animals than large, high input, migratory operators who were able to move flocks between summer and winter pastures. Furthermore, studies of populations of wild ungulate populations in the Rocky Mountains, showed that diverse vegetation could support larger populations of animals. Similarly, our analysis of cattle diets in northeast Queensland showed that animals with access to a more diverse mix of vegetation were better able to maintain diet quality through the dry season.

Current research: spatial diversification in rangelands

In Australia, there have been historic trends to fragment rangelands over the past century by subdivision into increasingly smaller land tenure units. This process has been strongest in the most productive rangelands (in the south east). Fragmentation has been driven largely by government policies aimed at developing rangelands, increasing productivity of land and enlarging rural populations, but has often been further compounded by unrealistic expectations of the productive capacity of land (especially during runs of good years or booms in commodity prices). However, there is now a trend to consolidation in the pastoral industry with an increasing number of enterprises expanding to operate across multiple properties. Not only does this allow economies of scale, but it allows restoration of the benefits of broad scale access to resources. Enterprises can use spatial diversification to select networks of properties with complementary mixes of resources (e.g., breeding and fattening country).

Another benefit is the potential to reduce exposure to climate variability by strategically pairing together properties with different weather patterns to reduce the chance that both properties will be affected by drought at the same time. This has formed the basis for a new project (funded by Land & Water Australia) to demonstrate the benefits of vegetation diversity in rangelands. We have been developing analyses to identify beneficial pairings of properties and how they can be used to help cope with drought. We are currently recruiting pastoralists who manage multi-property enterprises to participate in this new study, to provide case studies to test this drought-coping strategy by providing information to help plan future property purchases.