LANDSCAPE LOGIC

LINKING LAND AND WATER MANAGEMENT TO RESOURCE CONDITION TARGETS

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# Can Bayesian Networks aid analysis of survey data: A case study in the Wimmera, Victoria

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Cover photo: Wheat harvest in the Wimmera, 2008. [Photo: DSE]

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**LANDSCAPE LOGIC** is a research hub under the Commonwealth Environmental Research Facilities scheme, managed by the Department of Environment, Water Heritage and the Arts. It is a partnership between:

- **six regional organisations** – the North Central, North East & Goulburn–Broken Catchment Management Authorities in Victoria and the North, South and Cradle Coast Natural Resource Management organisations in Tasmania;
- **five research institutions** – University of Tasmania, Australian National University, RMIT University, Charles Sturt University and CSIRO; and
- **state land management agencies in Tasmania and Victoria** – the Tasmanian Department of Primary Industries & Water, Forestry Tasmania and the Victorian Department of Sustainability & Environment.

The purpose of Landscape Logic is to work in partnership with regional natural resource managers to develop decision-making approaches that improve the effectiveness of environmental management.

Landscape Logic aims to:

1. Develop better ways to organise existing knowledge and assumptions about links between land and water management and environmental outcomes.
2. Improve our understanding of the links between land management and environmental outcomes through historical studies of private and public investment into water quality and native vegetation condition.

# Can Bayesian Networks aid analysis of survey data: A case study of a landholder survey in the Wimmera, Victoria

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## Summary

This report describes an exploratory study comparing Bayesian Networks (BNs) with more traditional analytical techniques to interpret data from a survey that explored the land management practices of private landholders in the Wimmera region of Victoria. Using survey data it was possible to explore the impact on implementation of a range of policy instruments typically employed by Natural Resource Management (NRM) organisations in Australia. This study was also used to test the application of BNs to social research prior to a study of the drivers of vegetation change across three (NRM) regions in northern Victoria, described in a previous report in this series (Duncan *et al* 2007).

Interest in using BNs in Landscape Logic was prompted by the recent trend towards outcome based reporting in Australia with its focus on reporting change in environmental condition rather than activity and spending (Hajkowicz, 2008). Australia's 56 NRM regions are required to report to the federal government on the environmental impact of their management decisions. To date, this has typically taken the form of output reporting, describing the nature and amount of investment made and the resulting on-ground activities. The policy of outcome reporting means that regions are seeking ways to improve their understanding of causal relationships between intervention and environmental condition and collect data that measures that change.

Bayesian Networks (BNs), also called Bayesian Belief Networks (BBN) and Bayesian Decision Networks (BDN) were selected for this study as they are capable of integrating quantitative data and expert knowledge from different sources to map causal pathways. In this case, between management decisions by landholders and the range of factors expected to influence those decisions. While BNs are being increasingly used to model the biophysical, social and economic impacts of natural resource management strategies (Cain *et al,* 1999), they are not yet widely used to explore the influence of social factors on the implementation of conservation practices by rural landholders.

It was found that the use of BNs increased the depth to which social researchers could interpret their data, improved their ability to communicate the implications of the study to their peers and stakeholders, and provided a means to articulate their understanding of causal relationships in a form that could easily be transferred to and used by managers.

## Acknowledgements

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# Contents

# Introduction

## Adoption of NRM practices in Australia

Private landholders manage a large proportion of most Victorian catchments (Commonwealth of Australia 2002). Affecting behavioural change in private landholders is a complex task, with a large number of potentially influential factors affecting decision-making. Indeed, even the concept of adoption is problematic in that landholders may trial but not commit to a practice, or may implement part of a new technology and eventually may move on to another. While implementation decisions are complex and differ for each technology and each landholder at a particular point in time, a widely cited synthesis paper (Pannell et al, 2006) provides a useful framework for exploring adoption. This framework is provided below with examples:

1. Nature of the practice, including its trialability, observability, complexity and extent of re-skilling, the extent that it fits with existing farming systems and lifestyle, the cost and the time for returns to accrue, and whether it is a substantial improvement on what already exists,
2. Personal characteristics of landholder and their immediate family, including their occupation (farmer/non-farmer), education levels, knowledge, skills, length of experience in the area and/or the extent to which they identify as a farmer; level of income, stage of life, extent they are risk takers, whether they are introverts or extroverts, if there is to be farm family succession, and extent of their personal network,
3. Wider social context of the landholder, including prevailing norms, information flows through networks, the existence and activities of local organisations, and the level of trust in extension agents, and
4. Nature of any intervention/learning process, such as a regulation, market-based instrument, grant program, and group processes.

Governments have assumed that, at least in part, limited implementation of recommended conservation practices have occurred because landholders were unaware of important land degradation issues; lacked sufficient knowledge and skills; or had attitudes that emphasised short-term economic returns over maintaining the long-term health of the land (MDBC 1990; ASCC 1991). There has been a large investment of resources over the past decade in awareness raising and education programs, including those carried out by landcare groups. There is credible evidence that these activities do contribute to increased awareness and understanding and that these changes enhance landholder capacity to implement recommended practices (Vanclay 1992; Curtis and De Lacy 1996; Curtis et al, 2001a).

Some landholders have lifestyles and values that limit their response to approaches that focus on increasing agricultural production and profit maximisation (Barr et al, 2000; Curtis et al, 2001b). Non-farmers and retirees may respond less quickly to economic signals; be more averse to risking off-property income in on-property enterprises; and will probably have less time for property management (Barr et al, 2000). On the other hand, non-farmers may bring new ideas, skills and financial resources that contribute to the renewal of local communities and they may be more likely to respond to appeals for biodiversity conservation (Curtis and De Lacy 1996; Curtis and Robertson 2003). These are important considerations for catchment managers given the trend towards rural lifestyle properties in many areas of Victoria (Barr 2005).

Low farm income will constrain the capacity of landholders to respond to new opportunities. There is increasing evidence that many rural landholders have limited farm income and that this is a critical constraint to implementation (Barr et al, 2000; Curtis et al, 2001a). Poor returns from grazing have meant that landholders could not afford the fertiliser and remedial lime required to maintain pastures and prevent the downward trend in feed production that in turn affects water uptake and eventually, farm income (Millar and Curtis 1997). It is also unlikely that many dryland properties will generate substantial income from new enterprises such as olives, wine grapes and farm forestry (Stirzaker et al, 2000; Curtis et al, 2000).

Lack of confidence in current recommended practices (CRP) has been identified as an important constraint affecting implementation (Curtis et al, 2001b). Many CRP or alternate enterprises are either unprofitable and/or unsustainable. Problems arise if CRP or new enterprises are complex, are perceived as being risky, do not fit with existing enterprises or conflict with existing social norms (Vanclay 1992; Curtis and Race 1996; Barr and Cary 2000; Pannell et al, 2006). Landholders are also very reluctant to take on new enterprises that will involve entering long-term agreements with powerful industry partners, as is the case with farm forestry where there are often regional monopolies (Curtis and Race 1996).

Landholders are also increasingly aware that they are being asked to implement work that has community benefits through biodiversity conservation, improved public health and protecting export income (agriculture and tourism) and infrastructure. They also understand that many of the

problems that they are being asked to address have in part resulted from previous government policies. Establishment of the Natural Heritage Trust (NHT), with the Federal Government sharing the costs of large-scale on-ground work on private land, was an acknowledgment of the legitimacy of these arguments (Curtis and Lockwood 2000).

Discontinuity between the source and impact of issues, particularly those related to water degradation, adds a further complication. Many landholders in the upper reaches of catchments are either not experiencing these problems, believe they can live with them or are unaware or unconcerned about contributing to downstream impacts (Curtis et al, 2001a).

Australia has an ageing rural population with many of the new settlers being retirees, life expectancy increasing and younger people drifting from rural areas to the more prosperous and attractive lifestyles in urban centres (Haberkorn et al, 1999). We can no longer assume that a substantial proportion of the intergenerational transfer of properties will occur within families. Where family succession is unlikely, current property owners may be less willing to invest in CRP or new enterprises. Guerin (1999) and Curtis et al, (2001a) found that there was no clear correlation between landholder age and adoption, and suggested this was an important area for future investigation.

## Conventional techniques for social data analysis

This section considers techniques for analysing social survey data as opposed to collecting or eliciting social data, such as survey techniques. A large body of literature exists on the development of social surveys (e.g. Dillman, 1978; De Vaus, 2001, 2002).

### *Social-psychology models*

A number of theories grounded in social psychology have been identified in the literature as a means to explain adoption of technologies and conservation practices. This paper does not provide an exhaustive review of these theories. Instead it discusses a few key theories that have been used in the literature to examine factors affecting the adoption of production or conservation focused technologies. The theoretical and methodological basis for the adoption of conservation practices and/or new technology has been reviewed elsewhere in the literature (e.g. Vining and Ebreo, 2002).

*Theory of Reasoned Action/Theory of Planned Behaviour*

An extension of the Theory of Reasoned Action (TRA) (Ajzen and Fishbein, 1980), the Theory of Planned Behaviour (TPB) (Ajzen 1991) assumes that a person's intention to perform a behaviour (BI), is dependent upon their attitude toward performing that behaviour (AB), their subjective norm (SN) related to performing it (i.e. how much they think significant others want them to do it), and the perceived ease or difficulty in performing that behaviour (the 'perceived behavioural control (PCB)').

It can be represented as shown in Figure 1, or written as $BI = \gamma 1(AB) + \gamma 2(SN) + \gamma 3(PBC)$ where $\gamma 1$, $\gamma 2$, and $\gamma 3$ are empirically derived weights.

Typically, regression methods have been used to assess the relative contributions of explanatory variables to AB, SN and PBC (e.g. Lynne et al, 1995). The TPB has been used in the literature to relate landholders attitudes and motivations to land management (e.g. Lynne et al, 1995; Beedell and Rehmann, 2000; Karppinen, 2005, Fielding et al, 2005). For example, Fielding et al, (2005) used the approach to analyse survey data on landholders' management of the riparian zone in the Fitzroy Basin, Queensland.

These methods are not appropriate when the studied behaviours' are complex sets of actions, or if Likert scales (e.g. 'agree very strongly' to 'disagree very strongly') have been transformed to numerical ranks (e.g. 1 to 7) to analyse the significance of the difference in behaviour between landholder groups (Beedell and Rehmann, 2000; Karppinen, 2005). In its current state TPB does not allow for the inclusion of peoples' values.

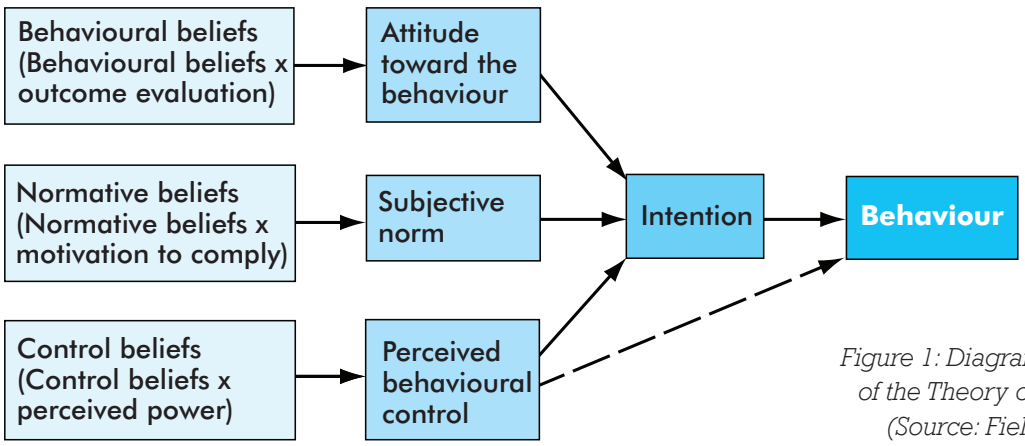



*Figure 1: Diagrammatic presentation of the Theory of Planned Behaviour (Source: Fielding et. al., 2005:13)*

*Cognitive Hierarchy Theory*

The Cognitive Hierarchy Theory (CHT) proposes that a person's actions are dependent upon their "values, value orientations (i.e. patterns of basic beliefs), attitudes/norms, behavioural intentions, and behaviours" (Vaske and Donnelly, 1999:524). These factors are said to build upon each other, and can be represented as an inverted pyramid, as shown in Figure 2. The CHT has been applied to NRM in the case of preserving wildland in the USA (Vaske and Donnelly, 1999).

*Value-Belief-Norm theory*

The Value-Belief-Norm (VBN) theory assumes that an individuals' behaviour is based upon their basic values, a belief that objects important to them are threatened, and a belief and sense of obligation (personal norm) that their actions can restore that value (Stern et al, 1999). As shown in Figure 3, one factor is believed to influence the next. The VBN theory has been used to explore the social movement in environmentalism (Stern et al, 1999).

*Summary*

Social-psychology models, like those presented here, can assist in data analysis by providing a structured and repeatable method with a sound theoretical basis, identifying beliefs that shape attitudes and motivations, and relating behaviour to underlying beliefs (Beedell and Rehmann, 2000). However, in isolation they do not represent the strength of relationships. This can be achieved when these models are coupled with statistical analysis (Section 2.2.3).

### *Statistical approaches*

*Regression models*

Regression models have been widely used to develop relationships between the adoption of technology or conservation practices and characteristics of farmers or landholders (e.g. land tenure, social capital, personal networks). Depending on the nature of the data, a number of forms of regression models have been developed (e.g. linear regression, discriminant analysis, tobit models, and logit

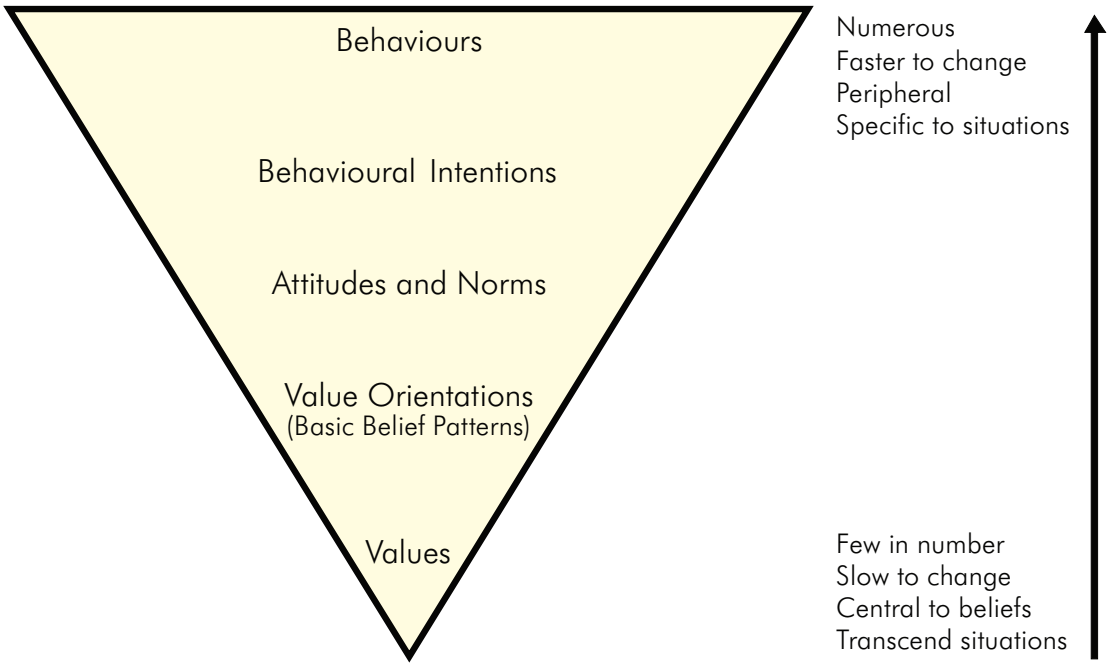



*Figure 2: Diagrammatic representation of the Cognitive Hierarchy Theory (source: Vaske and Donnelly, 1999: 525)*


*Figure 3: Diagrammatic representation of the Values-Beliefs-Norm Theory*

*Table 1. Types of regression models that have been used in the literature to determine relationships between the adoption of agricultural and/or conservation technologies or practices by landholders.*

| Technique | Overview | Examples |
|---|---|---|
| Multiple linear regression/ Ordinary least squares regression | Multiple linear regression estimates an equation of the form<br>$Y = a + b_1 \times X_1 + b_2 \times X_2 + ... + b_N \times X_N$<br>where Y is the dependent (or criterion) variable, a is the intercept, $b_1$ to $b_N$ are coefficients of the independent (or predictor) variables ($X_1$ to $X_N$).<br>*Key assumptions*<br>Linearity – linear relationship between variables<br>Normality – normally distributed residuals (predicted minus observed values)<br>*Advantages*<br>(Relatively) efficient use of data<br>Well-understood and interpretable theory and statistics<br>*Limitations*<br>The approach can not be used when the dependant variable is not continuous. Models can be heavily influenced by extreme values (outliers) although these values can be easily identified from analysis of the residuals, removed from the data set and the model recalculated | Curtis and Robertson (2003)<br>Bandiera and Rasul (2006)<br>Monge et al. (2008) |
| Discriminant analysis/ Discriminant function analysis | A variation of multiple linear regression analysis for prediction of the occurrence or non-occurrence of an event.<br>*Key assumptions*<br>Linearity – linear relationship between variables<br>Normality – normally distributed residuals (predicted minus observed values)<br>*Advantages*<br>Preferred option over logit models when the assumptions of linear regression are met because the model has more statistical power than logistic regression meaning there is less chance of accepting a false null hypothesis (type 2 errors)<br>*Limitations*<br>This technique can only be used with continuous independent variables. Independent variables need to be normally distributed, linearly related, or have equal within-group variances | Curtis and Robertson (2003) |
| Logistic regression/ logit model | The logistic regression approach is based on log odds and can be used when the dependent variable is either categorical with only two categories (e.g. yes/no) or continuous with values in the range of 0.0 to 1.0. The equation is of the form<br>$P = 1/(1+\exp(-(a + b_1 \times X_1 + b_2 \times X_2 + ... + b_N \times X_N)))$<br>where P is the computed value (a probability in the range 0 to 1) variable, a is the intercept, and $b_1$ to $b_N$ are coefficients of the predictor variables ($X_1$ to $X_N$).<br>*Advantages*<br>Preferred option (over discriminant analysis) where the independent variables are categorical, or a mix of continuous and categorical, logistic regression. Predictor variables do not need to be normally distributed, linearly related, or have equal within-group variances.<br>*Limitations*<br>Large sample sizes are required for logistic regression to provide sufficient numbers in both categories of the response variable (i.e. yes/no) | Warriner and Moul (1992)<br>Perz (2003)<br>Soule et al. (2000)<br>Cramb (2005)<br>Roberts et al. (2006)<br>Curtis and De Lacy (1996) |
| Probit model | A similar approach to the logit model although the probit model is based on the cumulative normal probability distribution. The dependent variable can only be 1 or 0.<br>*Limitations*<br>Less diagnostic tools than exist for logit models | Negatu and Parikh (1999) |
| Tobit regression/ tobit model | Tobit regression is intended for continuous data that are censored, or bounded at a limiting value.<br>*Key assumptions*<br>Normality – dependent variable is normally distributed but incompletely observed outcome (Smith and Brame, 2003)<br>*Limitations*<br>More vulnerable to violations of assumptions than ordinary least square regressions. Where errors are drawn from different distributions for different values of the predictor variables (i.e. heteroskedastic), the coefficient will be badly biased if a poor estimate of the error distribution is used to determine the chance that a case is censored. | Norris and Batie (1987)<br>Monge et al. (2008) |

models). A brief description of these forms is provided in Table 1.

Regression techniques allow the determination of relationships between variables and the relative importance of independent variables. They do not make statements about the underlying causal mechanism. Results from regression analyses need to be checked for their plausibility. This can include checking for a body of theory that suggests there should be a link, evidence of linkages in other studies, or feedback from stakeholders about evident links.

Other alternative causal explanations should be considered. Failure to do so in many studies has sparked criticism and concern about the interpretation of statistical analyses (e.g. Vanclay, 1986; Pannell et al, 2006). Regression analysis can also eliminate variables that assist in providing a plausible explanation for causality (Curtis 2009, pers. Comm.). To avoid this, a combination of regression modelling and other statistics, discussed below, can be used.

Multiple regression models (regardless of their form) require a large amount of data. The ratio of observations to predictor variables has been recommended as 10:1 and a much larger ration may be necessary to achieve stability of the regression equation (e.g. Osbourne, 2001).

*Other statistics*

Statistics used in the agricultural adoption literature to identify potential relationships between variables, either as stand-alone analyses, prior to development of regression models, or after applying a social-psychology model include the use of correlation statistics like the Pearson correlation coefficient (e.g. Curtis and Robertson, 2003; Monge et al, 2008) and Kendalls tau-b or non-parametric statistics like chi-squared (e.g. Molnar et al, 2001; Curtis and Robertson, 2003) and Mann-Whitney U tests. These statistics are easy to perform in order to identify the strength of relationships between variables but on their own they are unable to represent causality.

## Bayesian Networks

Bayesian Networks (BNs) are one of many techniques available to integrate data, knowledge and information from different sources, disciplines and points of view (See Letcher and Weidemann, 2004 for examples of integration techniques). They are considered to be one of the more simplistic integrative approaches, where each process in a complex system does not need to be explicitly represented (Borsuk et al, 2004).

BNs are developed to represent a system through a series of variables joined by causal links (Pearl, 1988). A distinctive feature of BNs is that causal links are described using probability distributions. The probability distributions can be determined using both quantitative (observed data, mathematical relationships or model simulation results) and qualitative (expert and local knowledge) information (Varis and Kuikka, 1997). A review of the use of BNs in water resource modeling and management can be found in a special issue of Environmental Modeling and Software, introduced by Castelletti and Soncini-Sessa (2007a).

The advantages and disadvantages of using BNs in Natural Resource Management (NRM) are discussed in Ticehurst et al, 2008. These include:

### *Advantages*

- They provide a conceptual representation of cause and effect and quantify the strengths of those relationships.
- Being able to incorporate quantitative and qualitative data makes the approach suitable for integrating social, ecological and economic factors to examine complex issues (Bromley et al, 2005),
- The probability distributions attempt to reflect the inevitable uncertainties associated with the impact of variables on one another (Varis and Kuikka, 1997). This allows the user to make a judgement on the reliability of the model predictions,
- The process used to develop BNs, shown in Figure 4, is well suited to facilitate stakeholder participation in the development, testing and use of the model,
- The states or classes used to define each variable in the BN can be used to determine thresholds relevant to decision makers (e.g. a threshold in annual income below which people will no longer invest in NRM on their properties),
- They provide a means of documenting current understanding and assumptions of how a system works which can then be reviewed and updated, thus constituting a record of growing systems knowledge, and
- They are well suited to the process of adaptive management where managers are encouraged to plan, implement actions, monitor results, and review and update plans (Smith et al, 2007).

### *Disadvantages*

- The states or classes used to define each variable, if poorly defined, can mask the impact of a particular scenario or input condition, and
- A poorly structured BN may not be able to provide insight into the issues of concern, and may also mask some of the important impacts from different scenarios.

Although the last two points above are identified as disadvantages of BNs, they are common to all integration or modelling techniques. Poor structure and definition within the BN can be identified during the testing and review of the functioning BN (Step 6, Figure 4). This includes a sensitivity analysis that identifies the key variables driving the BN, which are reviewed by the appropriate stakeholders and experts to ensure that they make sense.

Bromley et al, (2005) noted that BNs are most useful when data from different disciplines are being integrated together. If a problem is restricted to one discipline, particularly where there are sound physical, biological or mathematical laws (or models) describing relationships and processes, then other approaches may be more appropriate.

Although BNs have not been used in social research extensively, one example is the work by Castelletti and Soncini-Sessa (2007b). They developed an integrated model of a water reservoir network by coupling a social BN to hydrological models. The simple BN in the integrated model represented farmers' behaviour in the irrigation districts. Three variables, 'extension', 'expectation' and 'incentives', were found to determine the area of land cropped and the irrigation technique when farmers were faced with two crop options. The authors used a survey approach to elicit what farmers thought their reactions would be to the considered actions (extension and incentives) under different levels of expectations (low, medium and high). This approach was selected given that there 'were no physical laws describing farmers' response' (Castelletti and Soncini-Sessa, 2007b). Survey responses were then formalised in the BN.

Sebastiani and Ramoni (2001) developed BNs using data from the British Office of National Statistics to demonstrate the potential of the technique for analysing survey data. This annual survey provides information on population, housing, education, employment health and income. The BN developed from these data was able to show directed and conditional dependencies between network variables and, by propagating the network, undirected associations (Sebastiani and Ramoni, 2001; Sebastiani et al, 2005).

## Summary

Like social psychology models, the influence diagrams constructed during the BN development process are conceptual models of the relationship and processes that affect outcome variable(s). Unlike social psychology models, a wide range of variables including social, economic and/or environmental factors can be represented in the influence diagram. To account for these types of factors in social psychology models, relationships to the model parameters (e.g. AB, SN and PBC terms in the TPB model) need to be established. Regression modelling and other statistics can be used to identify and explore the strength of relationships between variables, but cannot on their own represent causality or multi-dependencies.

BNs can be easily used to explore the influence of variables in the network on other variables and outcomes, while showing the cause and effect throughout the network. The work of Sebastiani et al, (2005) and Castelletti and Soncini-Sessa (2007b) suggested that BNs are suitable for the analysis of social survey data on the uptake of conservation practices. This paper explores whether this technique complements or extends the knowledge gained, by researchers, managers and policy makers beyond that derived from more conventional statistical approaches such as regression techniques.

**Typical steps used to develop a Bayesian Network**

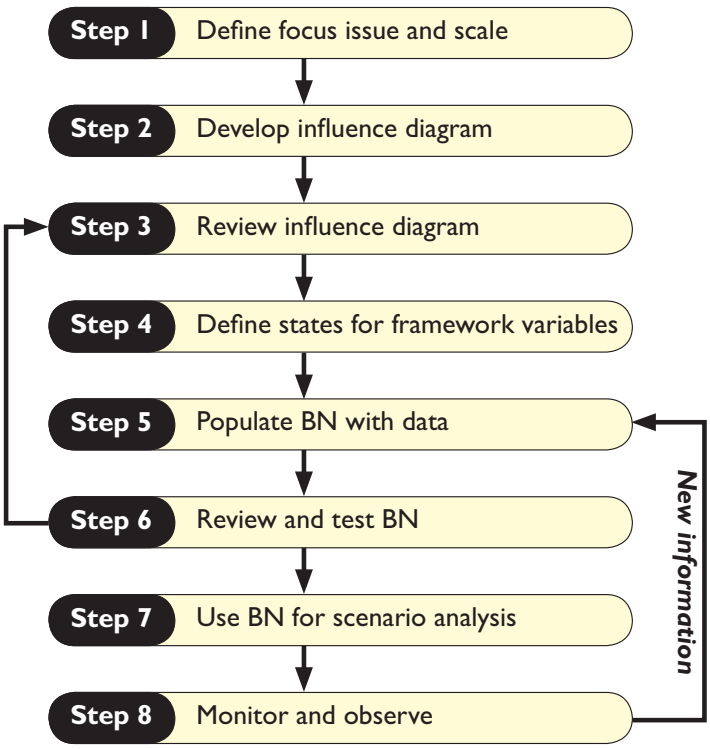



*Figure 4. Typical steps used to develop a BN. Influence diagrams developed and reviewed in steps 2 and 3 represent critical factors relating to a particular outcome (e.g. Vegetation Condition) (adapted from Ticehurst et al., [in preparation]).*

## Wimmera Catchment Management Authority region

The Wimmera catchment is located in the western part of the state of Victoria (Figure 5) and covers approximately three million hectares (20 per cent of Victoria). Landform in the Wimmera is typically gentle rolling plains interspersed in the south with a series of isolated volcanic hills (maximum elevation 750 metres).

The Wimmera River runs inland from these isolated hills in the south to a series of large terminal lakes in the north. The climate is typical of south-eastern Australia, with hot, dry summers and cool, moist winters. Winter rainfall increases and summer temperatures decrease towards the coast in the south. Eighty-five per cent of the native eucalypt forests and grasslands have been cleared to make way for European agriculture, mainly dryland crop and livestock farming based on cereals and sheep for wool and meat. Isolated but important pockets of native vegetation are protected in the public lands of the Little Desert and Grampians national parks and the Hindmarsh and Albacutya terminal lakes.

Primary production and associated processing industries are the main contributors to economic wealth. Tourism focussed on national parks and wineries is also an important industry. The population of the Wimmera is around 50,000 with almost a third of these people living on family farms or in small towns.

The major township is Horsham with a population of 15,000. The Wimmera Catchment Management Authority (WCMA) has identified the priority resource management issues as water erosion, dryland salinity, soil structure and soil fertility decline, increasing soil acidity, and introduced pest animals and weeds.

The Wimmera watershed has been divided into nine resource management units (RMU). Each RMU represents a part of the watershed that has similar landform, soils and vegetation. The WCMA has used these RMU as their basic planning units.

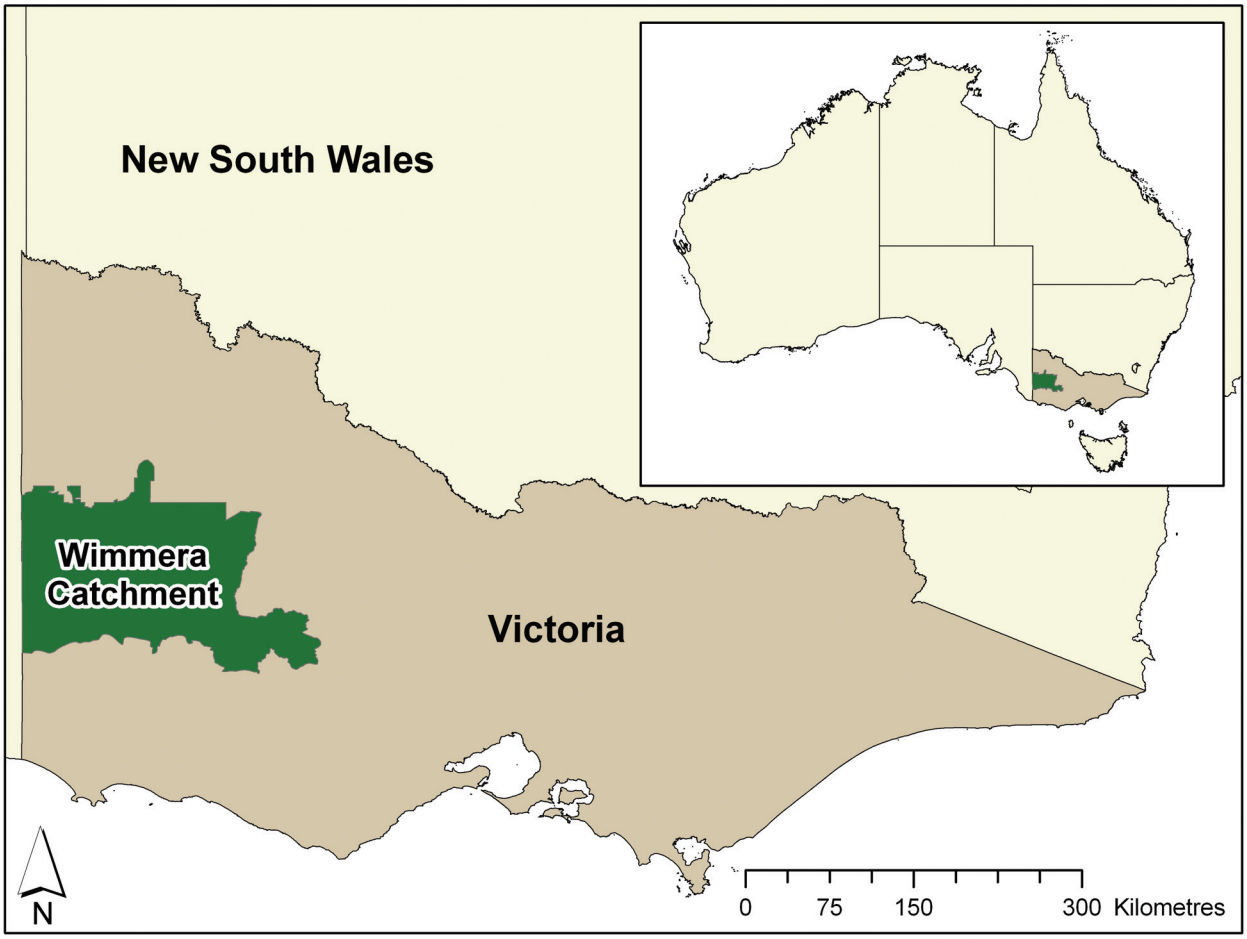



*Figure 5. Location of Wimmera region in south-eastern Australia.*

# Methods

An existing survey of the social drivers of conservation practices by landholders in the Wimmera region was use as the basis for this study (Curtis et al, 2008). Regression modelling and pairwise comparison statistics were used to quantify the drivers of adoption. For the purposes of this report, these analyses are referred to as the 'conventional analysis' as distinct from the 'BN analysis'.

## Project timeline

This exploratory study developed from an overlap of two projects, the Wimmera CMA social survey to describe the occurrence of the fencing of native vegetation, and the development of BNs in the Landscape Logic project to model the drivers of extent and condition change in native vegetation on private land. Figure 6 presents the timelines of each project and highlights where synergies were identified and the opportunity for this exploratory study became apparent.

## Social survey

The original 2007 social survey of land managers in the Wimmera CMA was carried out by Curtis and colleagues. Their experience working with regional organisations across three states suggests that social researchers can make important contributions to the knowledge base that underpins regional NRM. The NRM groups with whom they have worked recognise a role for social research to would assist them:

1. Identify and refine investment priorities;
2. Develop and improve engagement with private landholders;
3. Choose from amongst the mix of policy instruments available to accomplish resource condition targets; and
4. Evaluate the achievement of intermediate NRM objectives over time.

Of course, there are many ways to accomplish these tasks (Curtis et al 2005). The analysis of data collected through farm and household censuses can provide useful information, particularly about trends in the social structure of regions (Barr et al, 2000). However, as Schultz et al (1998) and Curtis et al (2001b) have demonstrated, these data are unlikely to satisfy regional NRM practitioners who need to understand the factors influencing property management by private landholders. In the first instance, these national data collection processes are unlikely to address most of the topics for which data are needed. The second major limitation is that data is typically only available at aggregates of 200 households or for each local government area. It is impossible to explore the factors affecting individual landholder implementation with these aggregated data sets.

Curtis and colleagues drew on their experience gathering spatially-referenced socio-economic data from mail surveys, and their knowledge of the extensive literature on adoption of sustainable farming practices, to refine a set of topics that would provide information to underpin key elements of the work of regional practitioners. Topics included in the survey of landholders in the Wimmera CMA were:

- assessment of issues affecting property and district
- self-assessment of knowledge for different NRM topics
- awareness of on-property dryland salinity
- values attached to property
- views about the roles and responsibilities of key NRM actors
- level of confidence in current recommended practices (CRP)
- preferred arrangement for involving landholders in NRM programs
- sources of information about NRM
- involvement in planning related to family succession and property planning
- long-term plans for the property
- land use/enterprise mix
- management practices on-property
- background socio-economic and property data, including: property size; age; gender; education; occupation; on and off-property work; on and off-property income; involvement in voluntary organisations; Landcare membership; membership of commodity groups; support from other sources for on-ground work; use of financial counsellors and consultants; involvement in short-courses; time lived in district; time owned or managed property; place of residence (absentee); and level of equity in property.

Local governments provided access to their ratepayer lists and these were used to compile a list of all rural properties greater than 10 hectares (the ten hectare threshold was used to separate rural and urban land use). These lists included a property identification field that supported spatial referencing of the survey data. The survey design and mail out process employed a modified Dillman (1978) *Total Design Method* process that has been refined through the experience of successive catchment surveys. Curtis et al (2005) provides a detailed explanation of the collaborative research process undertaken.

A 12-page survey booklet was developed in collaboration with regional partners, extensively pre-tested through workshops with landholders,

and then mailed to selected respondents. A list of 1,200 landholders was randomly selected from the lists provided by local governments. After removing multiple listings of properties and deceased estates, the final mailing list contained 1000 landholders. Of the surveys posted, 526 were returned completed, with 23 unusable. A final response rate of 56% was achieved (N=503).

Survey respondents were asked about their implementation of current recommended practices (CRP) for both sustainable agriculture and biodiversity conservation. CRP included in the survey were identified by CMA staff and participants in the survey pre-testing workshops as those practices expected to lead to improvements in catchment condition. CRP included in the survey can be classified into two groups: firstly, those principally related to biodiversity conservation (such as area of trees/shrubs planted); and secondly, those related to sustainable agriculture (such as cropping using minimum or not-til cropping).

Curtis and colleagues were conscious that some CRP are relevant to most landholders (i.e., non-specific, such as tree planting), while others are more relevant to particular landholders (i.e., specific such as implementing minimum tillage in

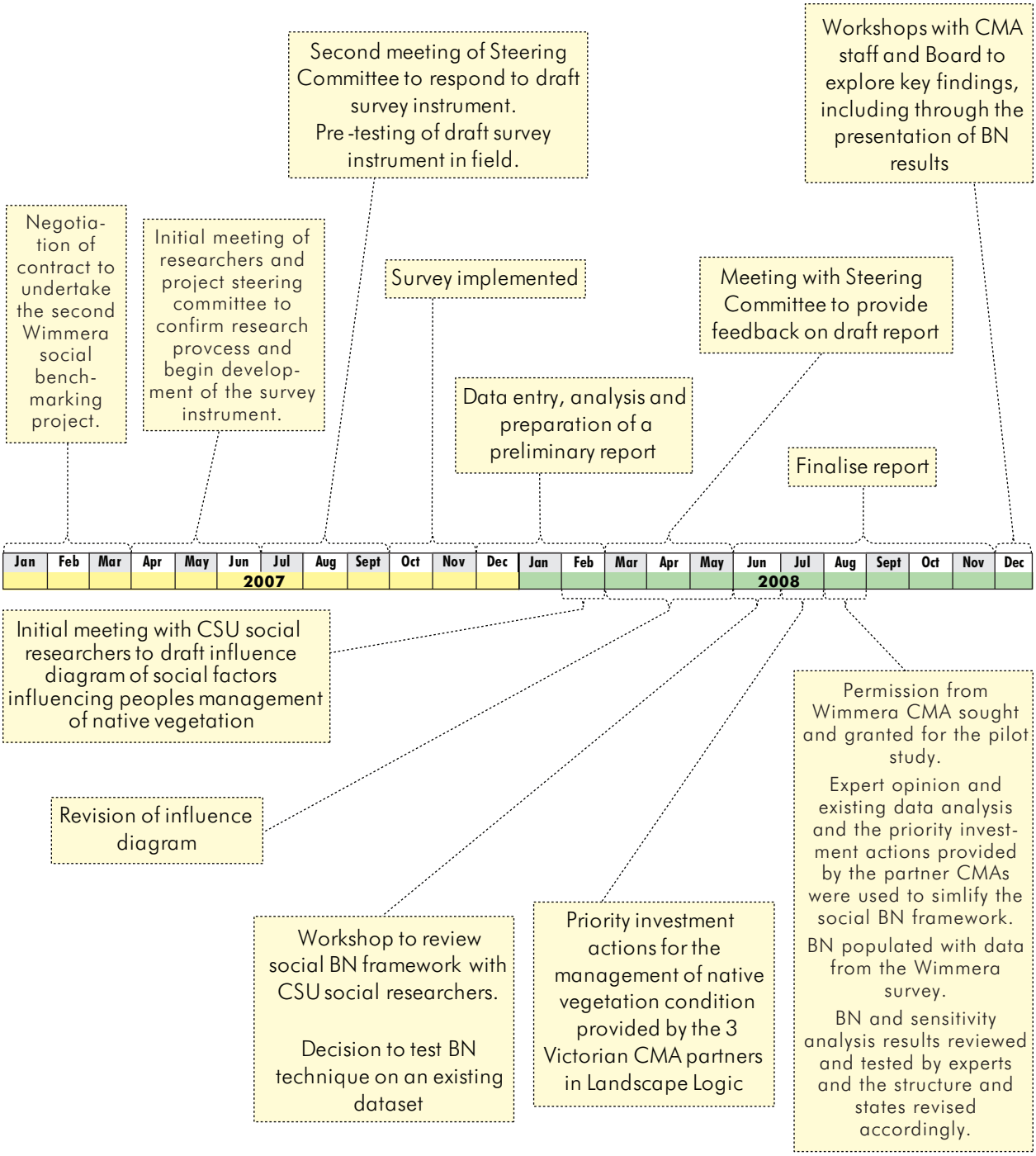



*Figure 6. Timeline of project(s)*

*Table 2. Statistical analyses of the Wimmera survey data (Source Wimmera Report)*

| Analysis/ Test | Description |
|---|---|
| Spearman rank order correlations | Used as an exploratory tool to search for relationships between variables as well as natural groupings (e.g. Why is the property important to respondent?) |
| Pearson's Chi-square | Used to compare categorical data against each other (e.g. Is there a relationship between completing a Property Management Plan (PMP) short course and how important the respondent believes native vegetation is on the property for providing habitat?) |
| Kruskal-Wallis Rank Sum | Used to determine the significant difference of a continuous variable based on a second grouping of variables (e.g. Is there any significant difference in property size between those who consider their occupation to be a farmer and those who don't [e.g. professional, trade, retiree, etc]?) |
| Multiple linear regression | Used to identify relationships between all continuous variables. (e.g. How long the respondent has lived in the local district and the size of their property) |
| Multiple logistic regression | Used to identify relationships when the dependent variable is categorical (i.e. yes/no) (e.g. Is there a relationship between the area of bushland fenced and if the respondent has a long-term vision for the property?) |

*Table 3. Strengths and potential limitations of the 'conventional analyses'*

*Strengths*

- Repeatable process
- Efficient and well-recognised technique for determining statistical relationships between dependent and independent variables
- Gives a measure of the strength of relationships

*Limitations*

- The main limitation with this method occurs if variables are correlated (Multi-colinearity issues) although if a significant problem exists it will be identified in the modelling process. Note that has not been identified as an issue with the Wimmera analyses.
- The final regression models for the Wimmera are one alternative and is likely one of many combinations that exist.
- Lastly, treating ordinal data as continuous data (e.g. 'strongly agree' = 1, 'agree' = 2, … , 'strongly disagree' = 5) assumes that the assigned values represent a real measure of outcome. That is, the difference between 'strongly agree and agree' is equal to the difference between 'disagree and strongly disagree'). This may or may not be appropriate.
- Regression identifies significant relationships, but not necessarily causal relationships. A combination of statistics, modelling and expert review is required to overcome this.

cropping systems). CRP were identified as specific to either cropping (such as direct seeding) or livestock grazing (fencing bush to limit stock access). All respondents were included in calculations of the percentage of respondents implementing the non-specific CRP but only those involved in cropping or livestock enterprises were included in calculations for the proportion of respondents implementing CRP specific to each type of enterprise, or in analyses exploring the factors linked to implementation of CRP. Specific survey items were included to explore implementation of the full period of a respondent's property management and others explored implementation over much shorter time frames, mostly the last five years.

## Conventional analyses

Curtis et al (2008) undertook statistical analyses to explore the factors affecting adoption of the following current recommended practices (CRP) identified in the WCMA Regional Catchment Strategy (RCS):

1. Use of minimum tillage for cropping
2. The use of no-till cropping
3. Area of gully erosion addressed
4. Establishing perennial pasture and lucerne
5. Off-stream watering points established
6. Fencing native bushland/grasslands to manage stock access
7. Fencing to manage stock access to waterways
8. Farm forestry
9. Planting trees and shrubs, including through direct seeding
10. Testing the quality of the main water source for stock/irrigation.

A summary of the statistical analyses performed on the Wimmera survey data is provided in Table 2.

Analyses were performed based on classification of each CRP as being either cropping or grazing specific or non-specific. Only respondents with relevant land uses were included in the analysis for each CRP. Fencing native bushland or grassland to manage stock access, the focus of this technical report, is non-specific meaning that all respondents were included in the analyses.

The process for the 'conventional analyses' was to consider each CRP and carry out pairwise comparisons with all variables to see which were significantly related. As the survey data are of different types – categorical, ordinal, scale, etc – the different tests in Table 2 were applied as appropriate. Any variables with a small response rate were removed from further analyses. Automated stepwise modelling was then conducted using the Akaike Information Criterion (AIC) to select variables. That is, linear models were constructed when the dependant variable (the CRP) was continuous or an ordinal scale and logistic models were constructed

when the dependant variable was categorical (i.e. yes/no). Strengths and potential limitations of conventional analyses are summarised in Table 3.

## Bayesian Networks analysis

Development of the BN followed the steps 1 to 6 of the process outlined in Figure 4.

**Step 1:** The Wimmera survey considered 10 current recommended practices (CRP) outlined previously. Consultation with the Victorian NRM partners of *Landscape Logic* helped to narrow down which management actions should be considered when developing the Wimmera BN. The main investment focus for the NRM regions involved in *Landscape Logic* are (1) fencing native bushland and grassland, (2) fencing to manage stock access to rivers, streams and wetlands and (3) tree and shrub plantings. This paper focuses on the fencing of native bushland and grassland to manage stock access, also referred to in this paper as 'fencing bushland'.

**Steps 2 to 6**: As part of the Landscape Logic project, work had commenced to document the drivers of native vegetation condition and develop an influence diagram to reflect their relationships. The resulting theoretical framework was highly complicated with a large number of nodes representing the technological, biophysical, demographic, economic and policy variables believed to affect a persons' willingness and capacity to change (Figure 7). The complexity of the influence diagram (40+ variables) limited the practicality and ease of developing it into a BN to support decision-making by NRM regions.

Results of the conventional analysis of the Wimmera survey data, together with expert knowledge, were used to develop a less complex influence diagram (13 variables), which was transferred into the Netica Software package www.norsys.com/netica.html). The size and structure of this second model reflected the type and volume of empirical data derived from the Wimmera survey. The data tables in the BN were directly constructed from the responses to the survey questions that were relevant to the fencing of native bushland and grasslands. A spreadsheet was developed that listed, for each of the 503 survey respondents, the state of each variable in the network.

Many different algorithms can be used when importing data into a BN in the Netica software. The simplest is counting, where the initial conditional probability tables are empty and the probability is tallied according to the results from each case. If the parents of any variable, or the variable itself, have a missing value then that case is ignored. One way to incorporate some of the missing data is to include 'missing data' explicitly as a state for each variable. Another algorithm that can be used when importing data into Netica is the Expectation Maximisation (EM). For this method the initial probabilities are assumed to be equal for each state, and the data is used to adjust the probabilities up or down accordingly. With this algorithm, the missing data are filled by using the trends shown by the existing data. If a dataset is a suitable size and complete, then the conditional probability tables using either method would be very similar. The impact of using the three algorithms (counting, counting + missing data, and EM) to populate the BN is explored in this paper.

A sensitivity analysis (SA) was performed for each variable in the network. The SA ranks the influence of each variable in the BN on the variable of interest (e.g. *Fence_bushland*) using the Mutual Information (or entropy) measure (for categorical variables) or the Variance of Beliefs measure (for continuous variables), both described in Marcot et al, (2006). A value of 0 indicates no influence on a variable whilst measure of 1 indicates a perfect causal relationship between two variables. Usually, variables that are directly linked to the variable of interest will have larger values that those variables not directly linked. Thus, the structure of the BN can strongly determine the results from the sensitivity analysis. To test the validity of the sensitivity results, the GeNIe software package (http://genie.sis.pitt.edu/) was used to learn the structure of the BN from the data alone. Initially all variables are assumed to be connected, and the data are used to either remove links between independent variables, thin links between weakly related variables, or thicken links between strongly related variables. The resultant BN gives a pictorial representation of the relative strength of relationships between dependent variables.

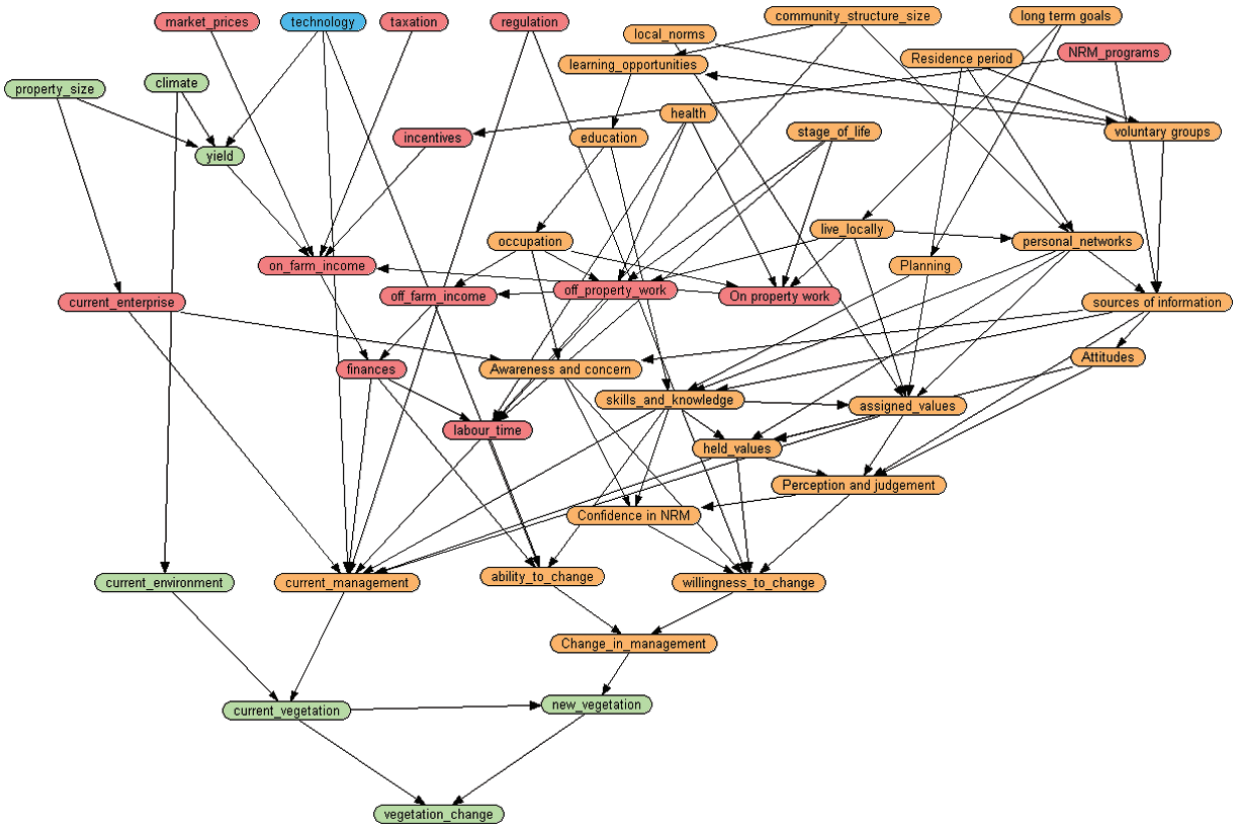



*Figure 7. Complex influence diagram of the social factors that impact upon native vegetation as part of the Landscape Logic project*

# Findings

## Conventional analyses

Analysis of the Wimmera survey data using the techniques outlined in Section 3.2 identified a number of variables that were related to the adoption of fencing native vegetation to manage stock access (Table 4). The level of significance is given by the p-value in Table 4 and in Figure 8: the smaller the p-value, the more significant the relationship. Having existing patches of bushland (ID 14) has been excluded from the analysis as it is a given that in order to be able to fence bushland, the bush must exist. The results show that government support (ID 11) had the most significant relationship with the fencing of bushland, followed by the property size (ID 9) and then having a long-term plan or vision for the property (ID 6). The least significant of the variables that were shown to have a relationship, was the enterprise (Beef [ID 12], then Lamb [ID13]) and then the occupation (ID10).

*Table 4. Variables that have the most significant relationship with the fencing of bushland.*

| Variable | p-value | ID[1] |
|---|---|---|
| A higher rating to 'native vegetation on my property provides habitat for native animals' | 4.5 x 10–3 | 1 |
| A higher rating to 'being able to pass the property on in better condition' | 6.9 x 10–3 | 2 |
| Higher self-assessed knowledge of the ability of perennial vegetation to prevent water tables rising | 6.6 x 10–4 | 3 |
| Higher self-assessed knowledge of how to protect and improve the health of native bush areas | 2.0 x 10–4 | 4 |
| Involvement in whole farm planning | 1.9 x 10–4 | 5 |
| Having a long-term plan or vision | 4.5 x 10–6 | 6 |
| Landcare membership or involvement | 1.1 x 10–4 | 7 |
| Membership of a local commodity group | 3.6 x 10–4 | 8 |
| Larger property size | 2.6 x 10–10 | 9 |
| Identifying as a farmer by occupation | 1.2 x 10–2 | 10 |
| Support from government | 1.1 x 10–16 | 11 |
| Beef cattle producers | 1.7 x 10–1 | 12 |
| Sheep meat producers | 2.1 x 10–2 | 13 |
| Have patches of native bush | N/A | 14 |

1. Reference ID used in Figure 8 and Table 5.

## Bayesian Network Analysis

The variables to be included in the BN were identified using knowledge of the significant variables identified by the 'conventional analyses' (Table 4), and expert opinion on other important factors affecting a landholders' decision to fence native vegetation on their property (Table 5). The assumptions underlying the structure of the BN are given in Table 6, and the resultant BN structure is shown in Figure 9.

Only 43% of respondents completed all of the survey questions relevant for this BN. The highest level of missing data was for the question regarding government support, where 43% of respondents did not answer the question (Figure 10). Therefore a lot of information can be lost if all cases with missing data are ignored, as is the case with the counting algorithm. Given this level of missing data, the

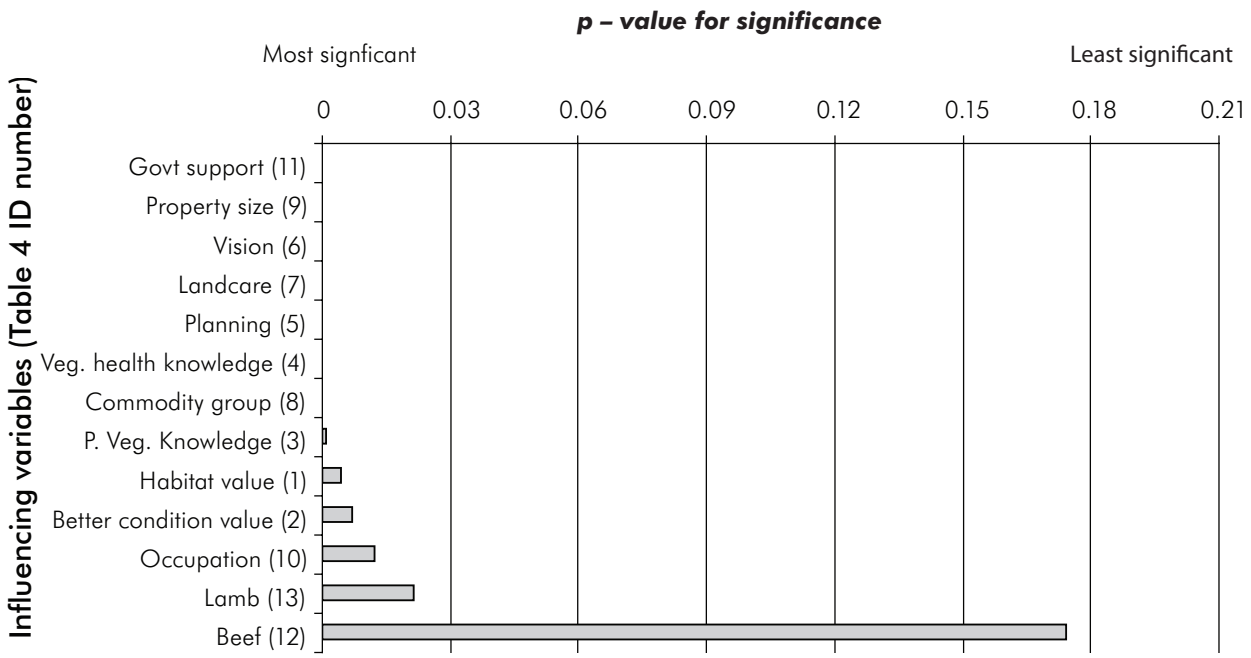



*Figure 8: Results from conventional analysis ranking the variables influencing the fencing of bushland, from the most to the least significant. The numbers in brackets correspond to the reference ID numbers given in Table 4.*

*Table 5. Assumptions behind the structure of the BN*

| Variables | Impacts upon | Assumptions | *Reason included |
|---|---|---|---|
| **Fence_ bushland** | N/A | N/A | |
| **Govt_support** | Fence_ bushland | With government support available landholders are more likely to fence bushland | T4 (11) |
| **Industry** | Knowledge | Which industry a landholder is involved with will impact what their area of knowledge is | T4(12&13) |
| **Knowledge** | Longterm_ vision | A landholders knowledge will impact their long-term vision for the property | T4 (3 & 4) |
| | PMP | A landholders knowledge will impact their Property Management Plan (PMP) | |
| **Labour_time** | Fence_ bushland | The more time spent on the property the more likely the landholder is to fence bushland | Exp Op |
| **Local_ organisations** | PMP | A landholder involved in local organisations is more likely to have completed a PMP course | T4 (7&8) |
| | Labour_time | A landholder involved in local organisations is likely to be able to access more volunteer labour (e.g. Landcare working bees) | |
| | Govt support | A landholder involved in local organisations is more likely to know what government support is available and how to access it | |
| **Longterm_ vision** | PMP | A landholders long-term vision for the property will impact whether they attend a PMP course | T4 (6) |
| **Occupation** | Govt support | Occupation influences whether the landholder knows where to find government support | T4 (10) |
| | Local organisations | Occupation will impact a landholders knowledge of the local organisations available and/or their capacity (time-wise) to contribute to the organisations | |
| | PMP | People who undertake certain occupations are more likely to have undergone PMP training | |
| | Labour_time | If you are a farmer you will spend more time on the farm | |
| | Values | Farmers value the land that they manage differently to non-farmers | |
| | Knowledge | Depending on your occupation you will have a different level of knowledge of your property | |
| | Onfarm_ income | Farmers have a different on-farm income than non-farmers | |
| | Industry | Farmers are more likely to partake in different industries than non-farmers | |
| **Onfarm_ income** | Fence_ bushland | Higher on-farm income will mean more money is available for NRM activities (i.e. higher capacity to change), but there is also evidence (Curtis pers. comm.) that on-farm income is more likely to be reinvested back onto the farm than off-farm income. | Exp Op |
| **PMP** | Fence_ bushland | A landholder who has attended a PMP course is more likely to fence bushland than one who has not | T4 (5) |
| **Property_size** | Onfarm income | The size of the property will impact the on-farm income | T4 (9) |
| | Labour_time | The size of the property will impact the time spent working on the property | |
| | Residence time | The size of the property influences whether it will be kept in the family throughout generations | |
| | Occupation | The larger the property the more likely that the landholder is a farmer | |
| **Residence_ time** | Govt support | A landholder who has been in the area for longer will be more likely to know how to find the government support whereas those who have recently arrived may not. | Exp Op |
| | Local_ organisations | A landholder who has been in the area for longer is more likely to be a member of a local organisation. Also the longer-term resident feels more committed to supporting local organisations and is therefore more likely to participate in activities, and adhere to local norms. | |
| | Knowledge | A landholder who has been in the area and on their property for longer will have a more in-depth knowledge of their property | |
| **Values** | Longterm_ vision | The values of the landholder will impact their long-term vision for the property | T4 (1 & 2) |

* Reason included: this variable was included in the BN because it was either identified as being significant in Table 4 (T4 with the ID number in brackets) or through Expert opinion (Exp Op)

*Table 6. The states, data source(s) and assumptions behind the data used to populate each variable in the BN*

| Variable | States | Survey question(s) | Assumptions in compiling BN data |
|---|---|---|---|
| Govt_support | Yes<br>No | During your management, have you receiving external funding to fence existing native vegetation? (yes/no) Have you received external funding over the last 5 years to fence existing native vegetation? (yes/no) | If the answer to either question is yes the response is labelled as yes (if the area was 0 ha it was assumed that the work is yet to take place) If no was recorded for either answer, and the other contained missing data, then the response is recorded as no. If the area recorded was greater than 0ha and the government support answer was missing, then government support was assumed to be no. Otherwise it was recorded as missing data and not included in the BN data. |
| Occupation | Farmer<br>Non-farmer | What is your main occupation? | If 'farmer' was mentioned in conjunction with another occupation, the response assumed for the BN was recorded as a non-farmer. Blank responses are recorded as missing data and not included in the BN. |
| Industry | None of the below<br>Lamb<br>Beef<br>Crop<br>Lamb & beef<br>Lamb & crop<br>Beef & crop<br>All | What is your current land use/enterprise mix? | Blank responses are recorded as missing data and not included in the BN data. |
| Residence_ time1 | <10 years<br>10 to 20 yrs<br>20 to 30 yrs<br>> 30yrs | How long you have owned/managed your land? How long have you lived in your local district? | The residence time is taken as the average of the number of years working on the property and the number of years they have lived in the region. |
| Onfarm_ income1 | < $50,000<br>> $50,000 | Did you property return a net profit (before tax) last financial year (2006/2007)? What is the approximate figure for the profit (before tax) from your property for the last financial year (2006/2007)? | The survey requires selecting a level of profit from 1 to 8, of these, <=5 is up to $50,000. $50,000 profit is the level of income assumed to be required to maintain a family, above which could be considered 'surplus'. |
| Values | Neither<br>Habitat<br>Better condition<br>Both | Is it important to you that the native vegetation on your property provides habitat for native animals ('habitat')? (Rank: 1 to 6) Is it important to you that you are able to pass the property on to others in better condition ('better condition')? (Rank: 1 [Not applicable] to 6 [Very important]) | For each question, rank values of 5 or 6 are recorded as important: a value of 1 was marked as missing data and not included in the BN data because it corresponded to a response of 'not applicable' and was not included in the conventional analysis. Rank values of 2 to 4 are recorded as not important. If both responses are important then the BN data is recorded as Both. If both responses are not important then the BN data is recorded as Neither. A record of Habitat means that the provision of habitat for native animals is important but it is not important to pass the property on to others in improved condition. A record of Better Condition means it is important to pass the property on to others in improved condition but that the provision of habitat for native animals is not important. If one response is missing the total response is marked as missing data. |

| | | | |
|---|---|---|---|
| Knowledge | Insufficient<br>Perennial vegetation<br>Vegetation health<br>Sufficient | Do you have the knowledge to use perennial vegetation to prevent water tables rising (Rank: 1 [Not applicable] to 6 [Very sound knowledge]) Do you have the knowledge to protect and improve the health of native bush area on your property (Vegetation health')? (Rank: 1 to 6) | For each question, rank values of 5 or 6 are recorded as sufficient knowledge to act upon: a value of 1 was marked as missing data and not included in the BN data because it corresponded to a response of 'not applicable' and was not included in the conventional analysis. Rank values of 2 to 4 are recorded as insufficient knowledge to act upon. If both responses are sufficient then the BN data is recorded as Sufficient. If both responses are insufficient then the BN data is recorded as Insufficient. A record of Perennial vegetation means that knowledge is sufficient only to use perennial vegetation to prevent water tables rising. A record of Vegetation health means that knowledge is sufficient only to improve the health of native bush area on your property. If one response is missing then the total response is marked as missing data and not included in the BN data. |
| Fence_ bushland | Yes<br>No | What is the area of native bush fenced to manage stock access (undertaken during your management)? What is the area of native bush fenced to manage stock access (last 5 years)? | If the area fenced for either question was greater than 0 ha the response was recorded as yes. If the area was 0 ha for both questions the response was recorded as no unless respondents had received government support. In this case it is assumed that fencing had been adopted but the work was yet to take place. The response is thus recorded as yes. If a response to one question was missing the response to the other question was used as the BN data response. |
| Local_ organisations | None<br>Commodity groups<br>Landcare<br>Both | Are you a member or involved with a local Landcare group? (yes/no) How many Landcare meetings/activities have you attended in the last 12 months? Are you a member or involved with any local commodity groups? | Responses are either yes to one ('commodity groups' or 'landcare'), no to both (none), or yes to both (both). If someone was not a member of Landcare but had participated in any Landcare activities then they were considered to be a yes for Landcare. If there was any missing data in the Landcare the total response was assumed to be a missing case and not included in the BN data. If there was any missing data commodity group membership the total response was based on the corresponding Landcare response (i.e none, Landcare or missing data). |
| Longterm_ vision | Yes<br>No | Do you have a long-term vision about the improvements you would like to make on your property? (yes/no) | Responses are taken straight from the survey. Blank responses are recorded as missing data and not included in the BN data. |
| Property_size[1] | < median<br>> median | What is the area of land you own? | The median property size is 630 ha. Blank responses are recorded as missing data and not included in the BN data. |
| Labour_time[1] | <15 hours<br>15 to 30 hours<br>30 to 50 hours<br>>50 hours | How many hours per week did you work on farming/ property related activities over the past 12 months? | 15 hrs was selected to represent non-farmers who work on the property only at weekends. 30 hrs (31 actually) is the median number of hours worked off-property by non-farmers, 50 hrs is the median number of hours worked per week on-farm by farmers. Blank responses are recorded as missing data and not included in the BN data. |
| PMP | Yes<br>No | In the past 5 years have you completed a short course relevant to property management? | There is not any follow-up as to whether the landholder have implemented a plan. Blank responses are recorded as missing data and not included in the BN data. |

1 These variables are continuous variables and the sensitivity analysis (SA) discussed in Section 4.2 uses the Variance of Beliefs measure to describe the relative level of influence on these variables. All other variables are categorical and the Mutual Information measure is used in place of the Variance of Beliefs measure in the SA.

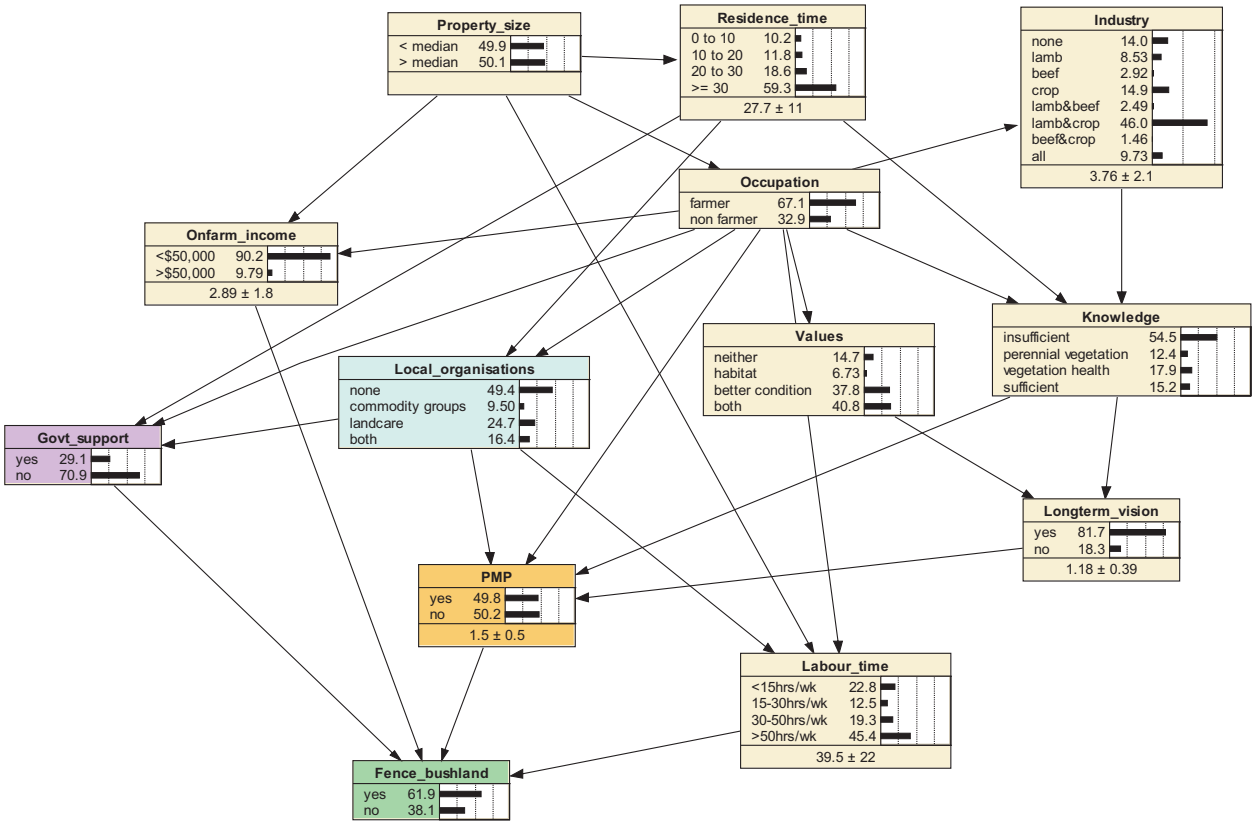



*Figure 9. Wimmera BN showing the structure and states*

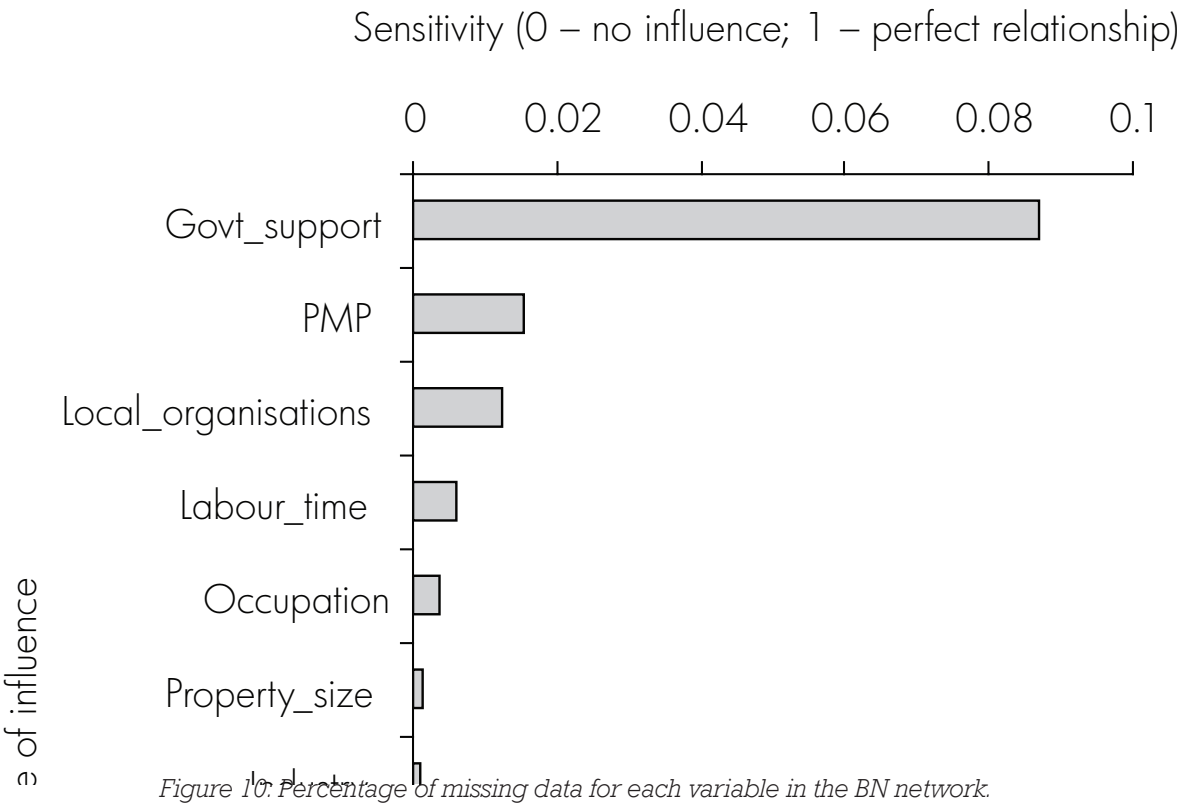



*Figure 10. Percentage of missing data for each variable in the BN network.*

*Table 7. The three most sensitive variables for each variable within the network. The shading represents variables that were linked in the GeNIe BN structure learnt from the data (Figure 12)*

| Variable | 1st | 2nd | 3rd |
|---|---|---|---|
| Fence bushland | Government support | Local organisations | Labour time |
| Government support | Fence bushland | Local organisations | PMP |
| Industry | Occupation | Labour time | Property size |
| Knowledge | Industry | Residence time | Long-term vision |
| Labour time | Occupation | Property size | Industry |
| Local organisations | Occupation | Labour time | PMP |
| Long-term vision | Values | Knowledge | Values |
| Occupation | Labour time | Property size | Industry |
| On-farm income | Property size | Occupation | Labour time |
| PMP | Local organisations | Local organisations | Labour time |
| Property size | Occupation | Labour time | Residence time |
| Residence_time | Property size | Local organisations | Occupation |
| Values | Occupation | Labour time | Industry |

*Table 8. Probability that fencing of bushland occurred given the states of its most influential variables. For example, setting the govt_support variable to 'With government support' and not setting any other variable in the network to a particular state gives a 87% likelihood of bushland being fenced.*

| Influential variables | Probability of bushland being fenced for each state | | | |
|---|---|---|---|---|
| 1. Government Support * | Yes (0.87) | No (0.52) | | |
| 2. Property Management Planning (PMP) course | Completed (0.69) | Not completed (0.55) | | |
| 3. Local organisations | Not a member of either (0.56) | Member of commodity group (0.67) | Member of Landcare (0.67) | Member of both Landcare and commodity (0.71) |

* Results shown in Figure 11

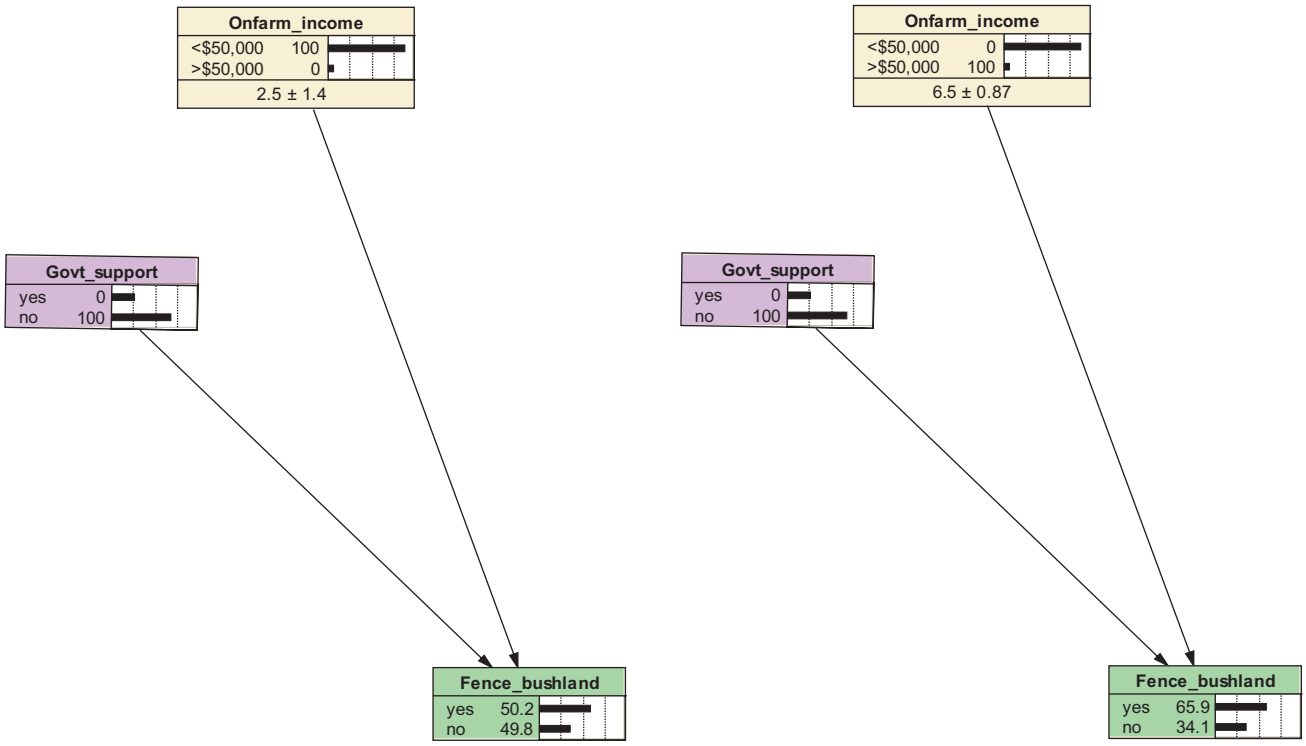



*Figure 11: Results from the sensitivity analysis using the counting, counting plus missing data and EM algorithms in Netica.*

algorithm chosen to populate the BN could have significant impact upon the results of the sensitivity analysis. However, Figure 11 shows that regardless of the algorithm used to populate the BN, government support was clearly the most sensitive variable to the fencing of bushland. *PMP, Local_organisation, Labour_time* and *Occupation* had a moderate impact on the adoption of the fencing of bushland.

The sensitivity results for *Onfarm_income* noticeably varied depending on the algorithm used to populate the BN. This is most likely due to the level of missing data for this variable (10% See Figure 10). This highlights that on-farm income is an important data gap which should be revisited in future research.

Given Marcot et al's findings (2006) the importance of government support to the adoption of the fencing of bushland could just be an artefact of the BN structure. However, the structure learning exercise conducted using GeNIe also showed a strong link between *govt_support* and *fence_bushland* (Figure 12). This confirms the strong relationship between these two variables is not a result of the predetermined BN structure.

The three most influential variables for each variable within the BN are given in Table 7 based on the sensitivity analysis. It shows that *Local organisations* is a common variable influencing the fencing of bushland (*Fence_bushland*) and government support (*Govt_support*), thus indicating a strong relationship between funding and community groups with respect to fencing bushland. The shading in Table 7 identifies which variables were directly linked in the GeNIe structure learning exercise. Of the possible 36 relationships in the table, 14 were also found to be linked in the learned structure. This suggests that the data on its own identified under half of the findings from the sensitivity analysis, but the importance of expert opinion in the development of a BN structure should not be under rated. One of the network variables included in the BN due to expert opinion, rather than significance in the conventional analysis shown in Table 4 (i.e. *Labour_time*, *Onfarm_income,* and *Residence_time*), was identified as having a significant impact on *Fence_bushland*. It would not have been included if it had not been identified by the expert review. In addition, as already discussed, *Onfarm_income* requires more research.

Analysis of the different algorithms used to populate the BN has shown that although there are some discrepancies between the BN and conventional analysis, the general findings are the same. The EM algorithm was used to populate the conditional probability tables in subsequent analysis of the adoption of the fencing of bushland to make the most use of the existing data. While missing data limits the information that can be used with the counting algorithm, and adding missing data as a state allows more data to be used to inform the conditional probability tables, the EM algorithm was found to produce

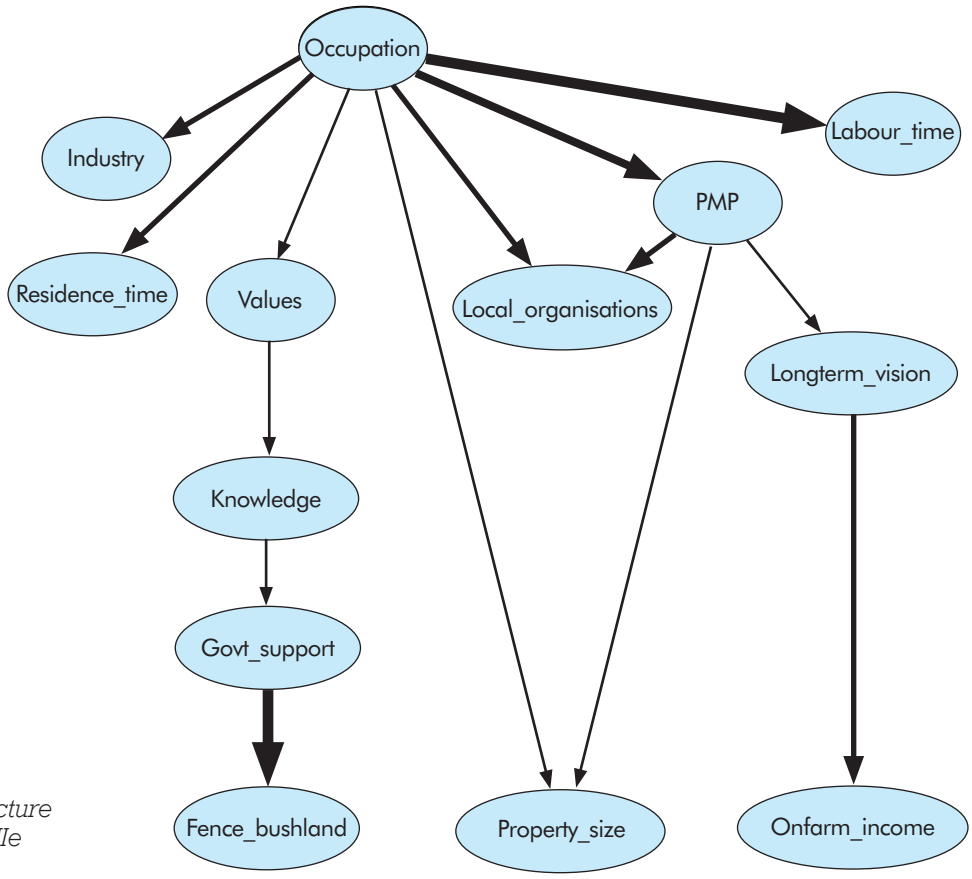


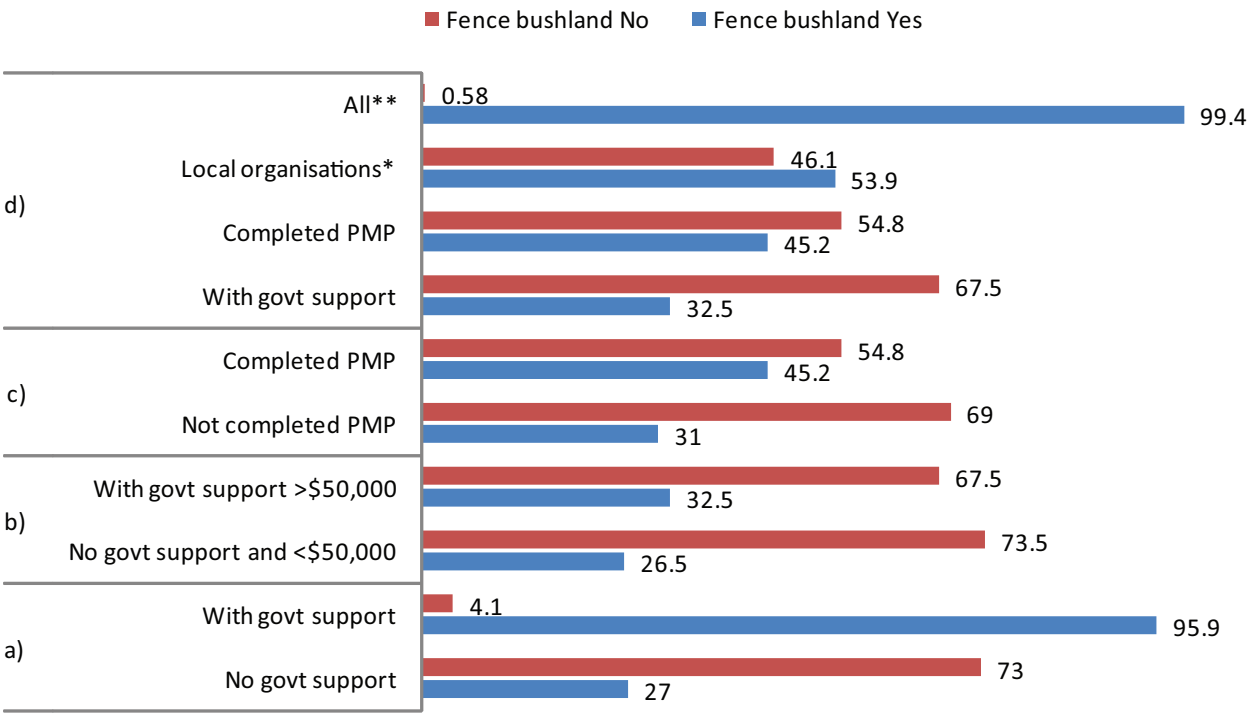

*Figure 12: Learned structure of the BN using the GeNIe software package*

the clearest and strongest relationships (Seen in the sensitivity results in Figure 11).

The BN suggested that with universal government support, 95.9% of respondents would fence native bushland, but without government support this decreased to 27.0% (Figure 13a). The economic importance of government funding is further shown by considering the adoption of fencing without government funding, by both low and high income landholders. Without government support, 26.5% of landholders with an on-farm income of less than $50,000 fenced native bushland, whilst only 6% more (32.5%) landholders fenced bushland if they had an on-farm income of greater than $50,000 (Figure 13b).

The BN suggests that completing a Property Management Planning (PMP) course influences fencing of bushland, increasing the likelihood that a landholder would fence bushland from 31% to 45.2% (Figure 13c). Similarly being a member of both Landcare and a commodity group increases the likelihood of fencing native vegetation from 29.9% to 53.9% (results not shown). At least part of the contribution of these groups is their involvement in trials and field days, where landholders can test the efficacy and explore the relevance of new practices with their peers under local conditions. These groups are also important in establishing norms about what "good farming in this district" involves. This indicates that in order to promote the fencing of bushland, money and technical support provided by the government, and the information, skills and confidence developed through the PMP course and local organisations are important. The BN suggests that collectively, government support, membership of a relevant local organisation(s), and completion of a PMP course would lead to a 99.4% likelihood of landholders fencing their bushland (Figure 13d).

Farmers were found to be less likely to have values relevant to the conservation of bushland than non-farmers, given that only 2.48% of farmers value habitat compared to 14.5% of non-farmers but were more likely to fence native bushland (42.6% compared to 28.2%, Figure 14). This can be partly attributed to the non-farmers being less likely to belong to Landcare or a commodity group (24.5% compared to 60.0%), less likely to complete a PMP course (19.9% compared to 61.4%), and less likely to spend more than 30 hours per week on the property (*Labour_time* = 12.2% compared to 92.9%), compared to farmers. This suggests that in relation to fencing bushland, farmers in the Wimmera are more influenced by training and social norms gained from the PMP course and local organisations than their values.




* *Local organisations refers to the membership of both Landcare and relevant local commodity groups*

** *All refers to having government support, completed a PMP course, and being a member of both Landcare and relevant local commodity groups.*

*Figure 13: The impact of (a) government support (b) low and high on-farm income without government support (c) completing a property management plan (PMP) course, and (d) government support, being a member of local organisations and completing a PMP course on the adoption of fencing bushland.*

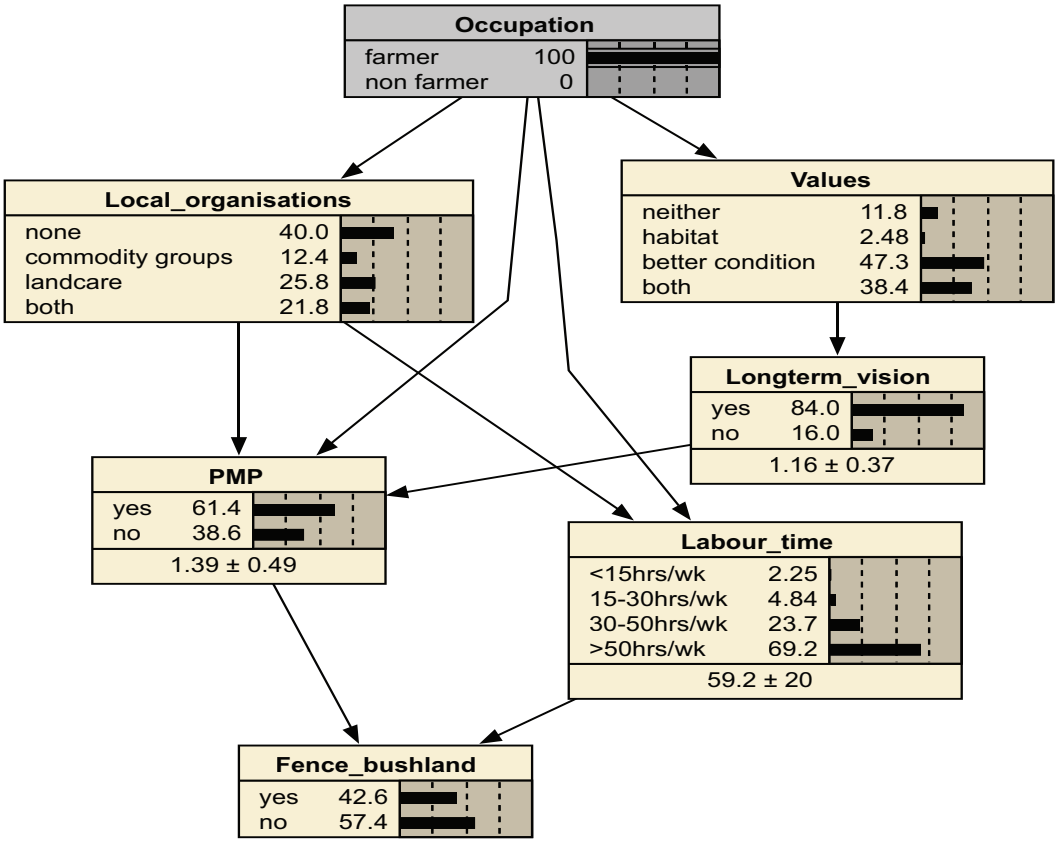
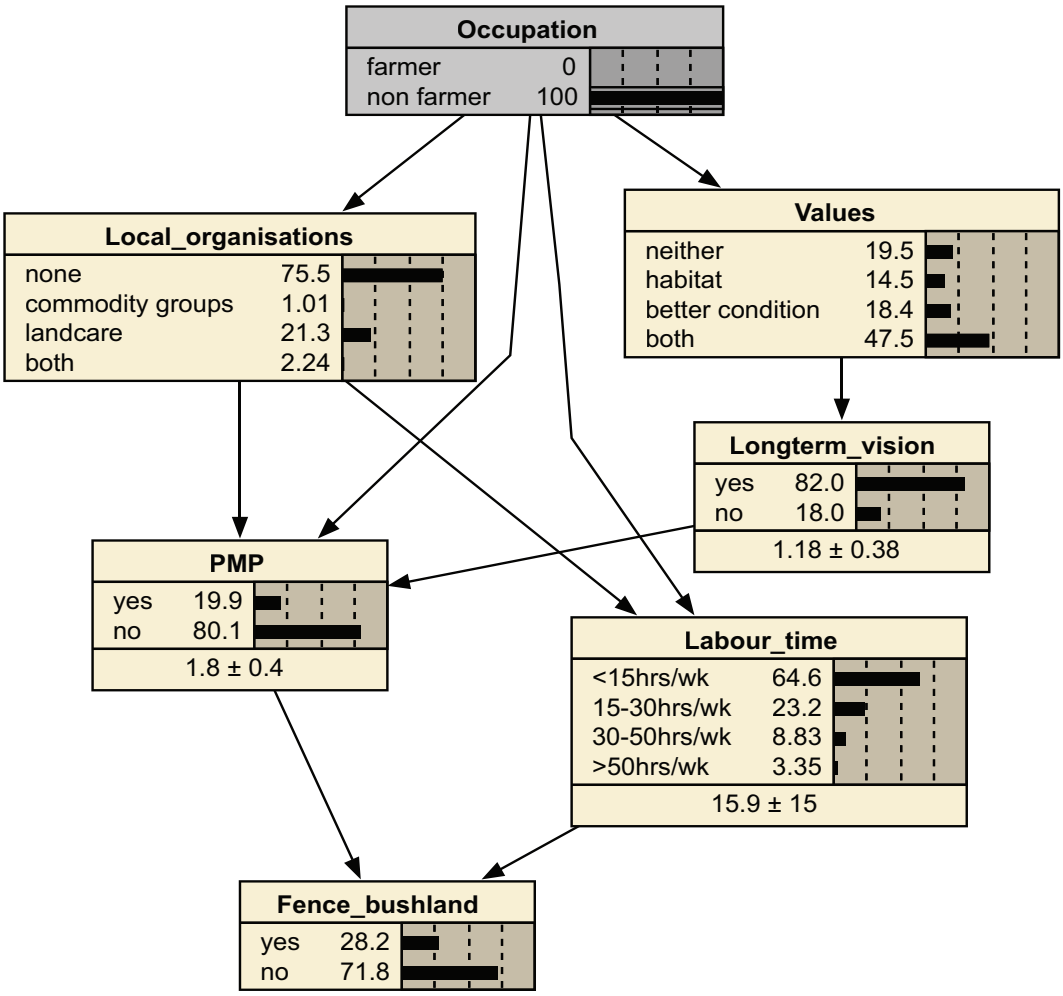



*Figure 14: The impact of occupation on values, self assessed knowledge, labour time , involvement with local organisations or PMP courses and the fencing of bushland. (Above: Farmers, Below: Non-farmers). This figure only shows some of the variables in the network for clarity.*



## Discussion

Both the conventional analysis and the BN analyses using the 3 alternative methods for populating the probability tables showed that the single variable that best explained the adoption of fencing bushland to manage stock access was government support.

The conventional analysis found the next most influential variables were property size and having a long-term plan and vision for the property. This is where the conventional and BN analyses differed, as next most influential variables using the BN analysis were membership of a local organisation (*Local_organisations*), time spent working on the farm (*Labour_time*), completing a Property Management Planning (*PMP*) course, or *Onfarm_income*.

The differences in the lesser significant variables are most likely to be due to the small values of significance which can easily change the rank of the results. Also, the way missing data was treated (i.e. counting, counting + missing data, or EM), influenced the analysis results. This highlights a feature of all model-based integration methodologies, which is that care must be taken to develop the best quality model possible from the data, particularly where there is incomplete or imperfect data. One way to ensure that a high quality model is produced and the results are appropriately interpreted is to fully utilise expert review throughout the process.

The BN analysis suggested that with universal government support the likelihood that land managers would fence bushland would increase from 27% to 95.9%. However, if the landholder was also a member of Landcare and a commodity group, and had completed a PMP course then this would increase to 99.4%. Non-farmers indicated that they had higher values associated with vegetation conservation, but farmers were more likely to fence their bushland (42.6% compared to 28.2%). This apparent contradiction is attributed to the greater involvement of farmers in local organisations and their higher rate of completing PMP courses.

The sensitivity analysis using the BN approach found that of the three variables added to the framework through expert opinion (i.e. *Labour_time*, *Onfarm_income* and *Residence_time*) only one (*Labour_time*) appeared to have a notable influence over the decision to fence bushland. This illustrates the value of the BN approach in enabling the influence of additional variables to be identified through expert elicitation and included in the analysis of the key drivers of adoption.

However, the differences between conventional and BN analysis went beyond the output of results in three distinct ways. First, the social scientists involved in the BN analysis found it was a particularly useful way to exploring causality (Curtis, 2008 pers.comm.). By providing a framework that made interactions between variables explicit, the researchers could collectively explore the relative influence of different variables on the adoption of the conservation practices. Second from the wider team perspective, constructing the BN helped the non-social scientists better understand and explore the relationships derived from the survey data and inferred by the social scientist. Third, by having all the interrelationships and assumptions used in the model open to the scrutiny of investors and policy makers, it increased the team's confidence in the model as a representation of this complex social phenomenon, and increased potential users confidence in its usefulness as a guide for management.

The graphical representation of BN approach was also found to be a very effective means of communicating the findings to NRM policy makers, and increased interest in social research and the use of BNs to re-examine existing data sets (Curtis, 2008 pers. Comm.).

The development of the BN was streamlined by the preceding conventional analysis. Without this, the initial BN would have no doubt remained more complex and required much more development and refinement. This iterative process has merit as a way of educating the participating stakeholders, but if time is limited and the expertise is available, then a combined approach using both a conventional and BN analysis can be utilised.

# Conclusions

To better target the investment of NRM funds to achieve change in natural resource condition, it is valuable to reflect on the impact of past attempts to influence management practice. This enables us to better understand the factors that influence landholder uptake of different conservation practices.

This report provides a summary of research that explored the potential for BNs to enhance our understanding of the relative influence of social and economic factors on landholder decision making. Data was collected using a survey of rural landholders in the Wimmera Region in 2007 that explored amongst other things, the adoption of fencing of native bushland and grassland to manage stock access. The results from a conventional analysis of the responses, plus expert opinion were used to develop a BN.

The conventional analysis and the BN analysis, regardless of the algorithm used to populate the probability tables in the BN, found government support to be of greatest importance in the adoption of fencing bushland. However, the two analytical techniques identified different variables to be the next most influential. Possible explanations for this variation are the small values of significance associated with the secondary factors and the alternative approaches that were used to handle missing data, which varied the ranking of secondary variables.

The BN was used to show relationships between a person's likelihood of fencing bushland and their values, knowledge and attitudes and access to government support and training. Government support had the greatest influence on the fencing of native bushland and grassland, with the BN suggesting that the likelihood of adoption would increase from 27.0% to 95.9% where it was universally available. Landholders identifying as farmers were more likely to belong to relevant local organisations (e.g. Landcare, commodity groups), complete a property management plan, have higher labour levels and more likely to access government support. Although farmers placed less importance than non-farming landholders on values such as habitat provision (BN results 2.48% farmers compared to 14.5% non-farmers, not shown here), the combined effect of the various influences resulted in farmers being more likely to fence bushland than non-farmers.

The development of this BN was facilitated by pre-existing survey data which empirically defined a set of factors that influence adoption, the knowledge gained from the conventional analyses of that survey data (Curtis et al, 2008), and the interaction of the BN team with the social scientist who carried out the survey. Without the prior learning and expert opinion, the initial conceptual diagram would have been more difficult to develop and potentially more complex. Once developed, the BN provided a useful tool for the interdisciplinary research team to structure and clarify the model and then communicate its results and implications to stakeholders in a way that is not possible with conventional analytical methods.

BNs are well-suited to adaptive development and can be progressively refined or simplified through sensitivity analyses and through the incorporation of additional expert opinion and other qualitative information. This approach also provides stakeholders with a useful opportunity for process learning. However, where resources are limited, an initial empirical data analysis can simplify and fast-track the development process. Therefore, where the expertise exists, a combined approach using both conventional and BN analysis techniques appears useful.

This report presents the findings from an exploratory study into the usefulness of BNs in the analysis of social data. Future work associated with the *Landscape Logic* project will use this approach to examine different environmental end-points in a range of different geographical and social settings to further test the value of this technique. This additional research will allow time for stakeholder review, and further refinement of the BNs, which is more typical of the process for regional development, as well as more time for the social researchers to reflect on what BNs might be able to add the use of more conventional analytical methods.

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