Report No 4

NPSI Project UMO45: Delivering Sustainability through Risk Management

Ecological Risk Assessment Case Study for the Lower Loddon Catchment: *Bayesian decision network model for predicting grey-crowned babbler population abundance in the Lower Loddon catchment*

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Executive Summary

This report - *Ecological Risk Assessment Case Study for the Lower Loddon Catchment: Bayesian decision network model for predicting grey-crowned babbler population abundance in the Lower Loddon catchment* - is the fourth in a series of five produced by NPSI project UMO45 *Delivering Sustainability through Risk Management*.

The ecological risk assessment conducted in this study was focused on the assessment of the ecological health of the Lower Loddon River and its catchment. The aim of the risk assessment was to provide local resource managers with a better understanding of risks to the Lower Loddon River and catchment, and the effectiveness of different management actions in protecting and rehabilitating the river.

A Bayesian decision network (BDN) model for predicting *river farmland ecological values* in the Lower Loddon River was developed and full details are provided in this report.

Farmland Ecological Values are defined as the value of farmland to the ecological assets of the larger catchment within which farms exist, but not values directly associated with agricultural production (i.e. the crops themselves are generally regarded as a separate 'value'). Specifically, the ecological values included the role of farmland and surrounding areas to wider biodiversity and to specific species of indigenous fauna and flora. This is essentially restricted to ecological uses of farmland for foraging or for habitat in the parts of farmland not affected by seasonal disturbances such as harvesting, such as shelter-belts or riparian zones preserved for stream water quality. Areas of farmland under direct cultivation are generally unsuitable for habitat.

The abundance of a common bird species - the *grey-crowned babbler* – was used as the measure of farmland ecological value, and a BDN model developed to predict population abundance of the grey-crowned babbler.

The structure of the BDN model was based on a conceptual map constructed by stakeholders in an initial workshop, and included four main factors that influenced population abundance of the grey-crowned babbler – habitat availability, food availability, biological factors and socio-economic factors. In the preliminary model reported here, socio-economic factors and some other variables (e.g. catchment landuse, groundwater quality, hydrology) were not included because of a lack of data and information, but could be included in the next iteration of the model.

The BDN model predicts that for existing conditions, there is a high probability of low population abundance of the grey-crowned babbler. Sensitivity analysis showed that poor habitat and low 'biological potential' (i.e. the effect of a combination of biological factors such as competition, reproduction and predation) had the greatest influence on the abundance of the grey-crowned babbler populations.

The model was also used to predict the effect of stock access on remnant forest area and on the abundance of grey-crowned babbler populations. Reducing stock access was predicted to significantly improve the probability of medium to high abundance of grey-crowned babbler populations from around 40% when stock access was high to around 81% for low access.

These results support the current Loddon catchment management plan, where major on-ground fencing works are being implemented to reduce stock access to the riparian zone and will be extended to include fencing of remnant catchment vegetation.

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1. Introduction

1.1 General

The National Program for Sustainable Irrigation (NPSI) is committed to improving the sustainability of current and proposed irrigation schemes throughout Australia.

In support of this aim, NPSI has funded project UMO45 *Delivering Sustainability through Risk Management*, which is designed to raise awareness of the Australian irrigation industry in adopting risk-based environmental management approaches. The adoption of risk-based approaches is considered to be vital if the industry is to achieve its goal of long-term sustainability. This project is a logical extension of an earlier NPSI project (UMO40) that developed an Ecological Risk Assessment framework for the Australian irrigation industry (Hart et al., 2005).

This *Delivering Sustainability through Risk Management* project aims to achieve an improved level of adoption of risk assessment and risk management approaches in environmental management and a greater capacity to use such approaches, within both the irrigation industry and regulatory authorities in Australia.

The project had three components:

- to undertake a series of *regional awareness workshops* aimed at explaining the objectives of this project, as well as the ways in which risk management might be adopted by the irrigation industry and how this will assist them to achieve the ultimate aim of long-term sustainability of the industry,
- to establish *case study partnerships* involving the irrigation industry and appropriate State irrigation regulators, and to work with these partnerships to develop capacity within the individual organizations to use risk assessment and risk management procedures to improve the ecological sustainability of the irrigation region, and
- to work with *selected Sustainable Irrigation projects* (and their key stakeholders) in trialing different methods and approaches for adopting risk management procedures into their projects.

Five reports have been produced by this project:

- Summary Report - *Delivering Sustainability through Risk Management* (Hart et al., 2006).
- Report 1 – *Prospects for Adoption of Ecological Risk Assessment in the Australian Irrigation Industry* (Walshe et al., 2006).
- Report 2 – *Ecological Risk Assessment Case Study for the Murray Irrigation Region* (Pollino et al., 2006).
- Report 3 - *Ecological Risk Assessment Case Study for the Lower Loddon Catchment - Bayesian decision network model for predicting macroinvertebrate community diversity in the Lower Loddon River* (Westbury et al., 2006).
- Report 4 - *Ecological Risk Assessment Case Study for the Lower Loddon Catchment - Bayesian decision network model for predicting grey-crowned babbler population abundance in the Lower Loddon catchment* (Chan & Hart, 2006).

These reports are all available at www.sci.monash.edu.au/wsc.

This document is Report 4 of the series. It reports the case study undertaken in the Lower Loddon catchment downstream of Bridgewater in northern Victoria.

1.2 Lower Loddon ecological risk assessment

The Lower Loddon catchment ecological risk assessment was a collaborative project involving staff from EPA Victoria, Water Studies Centre Monash University, North Central Catchment Management Authority (NCCMA) and Goulburn-Murray Water (G-MW). The project was assisted by funding from the National Action Plan for Salinity and Water Quality and the National Program for Sustainable Irrigation (NPSI).

The project aimed to:

- provide quantitative information to assist in natural resource management in the region,
- raise awareness about risk-based assessment methods, and
- provide a practical case study on the implementation of an ecological risk assessment (ERA) process.

Figure 1 provides a summary of the project approach and Figure 2 contains a map of the project area.

A major aim of the project was to provide information and decision support tools to assist NCCMA, G-MW and Department of Primary Industries (DPI) in targeting on-ground management actions and monitoring programs, for rehabilitation of the lower Loddon catchment. The focus and scope of the risk assessment was developed during the Problem Formulation phase of the project in collaboration with stakeholders with an interest in the Lower Loddon area (see Westbury et al., 2005b). The stakeholder group involved had considerable knowledge and experience in the management of the Lower Loddon Region, and included natural resource managers, landholders, regulators, local government and water authorities.

During the Problem Formulation phase, stakeholders identified two ecological values potentially at risk to be the focus of a quantitative risk analysis; these were the *ecological health of the Lower Loddon River* and *farmland ecological values.* This report discusses the development of a Bayesian Decision Network (BDN) model to predict the *abundance of grey-crowned babbler populations* as an indicator of *farmland ecological values* in the Lower Loddon catchment.

Stakeholders defined the area to be covered by the Lower Loddon River risk assessment as the Loddon River main channel downstream of Bridgewater (Figure 2).

The risk analysis involved the development of a Bayesian decision network (BDN) model for grey-crowned babbler population abundance in the Lower Loddon cathment. BDNs are ideally suited to assist in natural resource management decision-making, where problems are complex and data often scarce and uncertain. They are able to bring together and incorporate all available types of data, knowledge and information. This is all combined in the network to provide predictions of the overall risk posed to ecological values, and the likely outcomes under different management scenarios. The models can be easily updated when more information becomes available, increasing the understanding of catchment processes overtime. Most importantly, they provide quantitative predictions that explicitly state where the uncertainties are in the information.

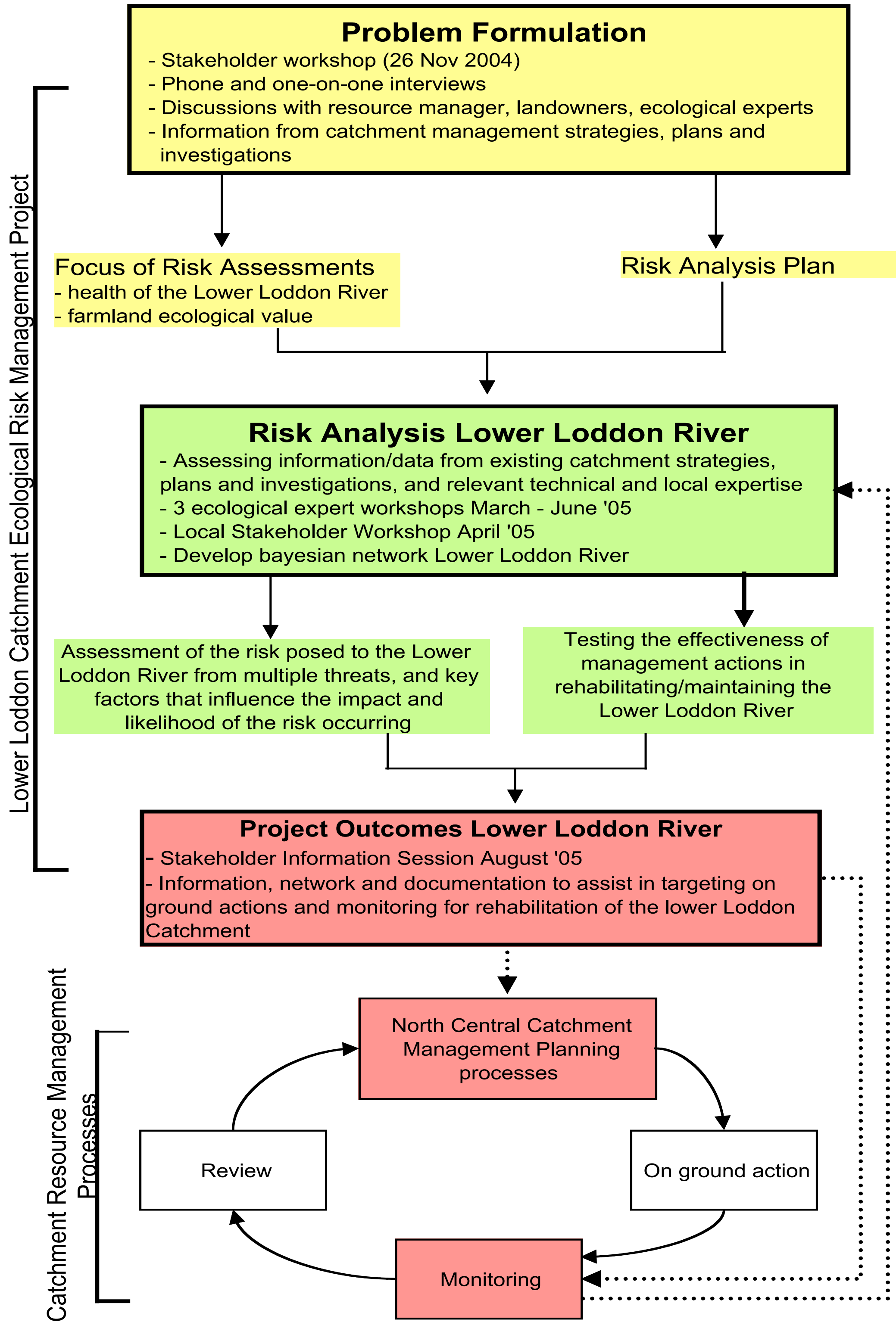

Figure 1: Summary of the Lower Loddon Catchment Ecological Risk Management Project, and linkage to North Central Catchment Management Processes

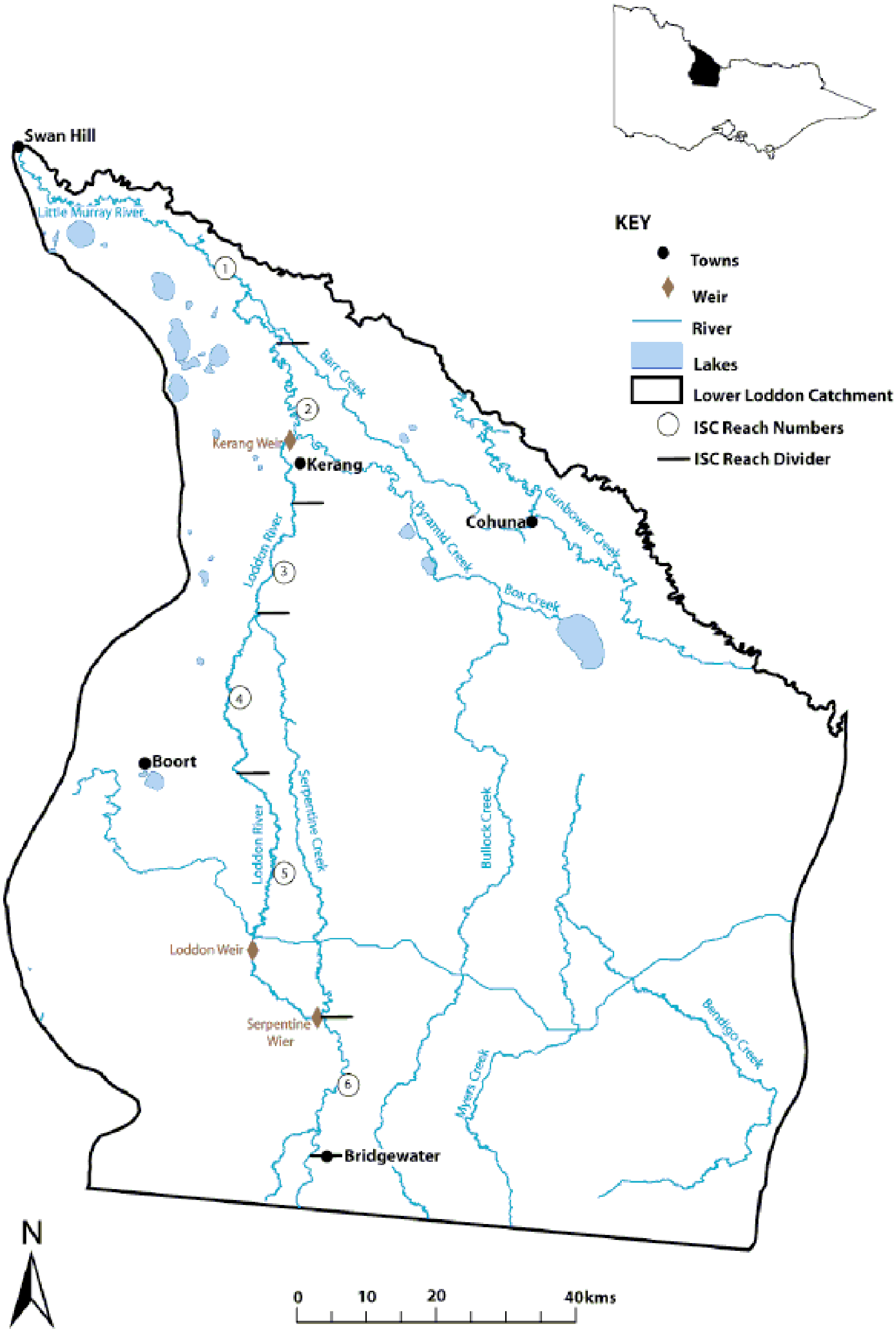

Figure 2: **Map of the Lower Loddon Catchment**

The information from the Bayesian decision network will provide the NCCMA, G-MW, DPI and landowners with a better understanding of risks to the Lower Loddon River and its catchment and the effectiveness of different management actions for its protection and rehabilitation. This information is to be used in conjunction with, and to support, existing catchment management plans.

2. Lower Loddon catchment

2.1 General

This project is focused on the lower Loddon catchment, downstream of Bridgewater (Figure 2). The major land uses in this region are irrigated and dryland agriculture. The irrigated agriculture is predominately dairy, horticulture and mixed farming, and the dryland agriculture is predominately cropping. The major urban communities are Kerang, Cohuna, Pyramid Hill, Boort and Swan Hill.

The Loddon River flows in a single channel from Laanecoorie Reservoir to just south of Serpentine, where the river enters the Loddon Fan. Here the Loddon becomes a series of anastomosing distributary streams flowing northwards across the Plain. The Bulldog Creek-Pyramid Creek in the east of the lower catchment enters the Loddon at Kerang. Barr Creek enters further downstream, and is slightly unusual in that it drains relatively high salinity groundwater. The Lower Loddon river flows through the River Murray floodplain before draining into the Murray in the north.

Approximately half the flow in the entire Loddon catchment is diverted for irrigation or for stock, rural, and domestic uses. The use of 110,000 ML from local surface water resources (mainly the upper catchment) accounts for about 8% of total use. About 95% of the total is used for irrigation, 3% for rural, stock, and domestic purposes, and 2% for urban and industrial uses. The greater part of the water use in the Loddon catchment is imported from the River Murray and Waranga Western Main Channel and the Coliban supply system. Water for the Torrumbarry irrigation system is diverted from the River Murray at Torrumbarry Weir into either Gunbower Creek or Kow Swamp. Water for the Pyramid-Boort System is supplied by the Loddon River or the Goulburn River via the Waranga Western Channel.

There are more than 60 water storages in the Loddon catchment, although most are small (<5,000 ML), with only three water storages with capacities greater than 50,000 ML, and only one of these (Kow Swamp) located in the Lower Loddon catchment. Some of the wetlands in the lower catchment are used as irrigation system storages, and some as evaporation basins (e.g. Lake Tutchewop) for reduction of salt discharge into the River Murray.

Irrigated agriculture is, and will remain the major economic driver for the foreseeable future, and produces valued dairy, meat, grain and horticultural products. There is also a significant part of the community that is not directly dependent on irrigation farm business for their livelihood. Additional direct economic values in the region include dryland cropping and grazing, timber production, apiculture, and recreation and tourism. Overall, agricultural output represents 70% of the economic value of the Lower Loddon region.

Water quality in the region is of concern as poor quality imposes costs on users (e.g. via restriction of irrigation supplies, or closing of recreational areas) and is also detrimental to aquatic ecological values. The Lower Loddon catchment has a naturally high salinity, although increasing dryland salinity is of concern. Stock access to waterways and agricultural runoff can increase turbidity and nutrient levels (Loddon River Environmental Flows Scientific Panel, 2002). Blue-green algal blooms occur regularly in the region (e.g. Lake

Boga), and the Loddon Catchment Water Quality Management Strategy has been implemented to reduce nutrient loads to the system in order to reduce the frequency and severity of blooms (NCCMA 2002).

The natural flow regime has been altered by significant diversions for irrigation. Estimates indicate that median flows have been reduced year-round, and the duration of extreme low flows has been increased. The seasonal pattern of flow remains similar to natural, and peak flows do not seem to be greatly reduced, although the magnitude of flood peaks appear reduced up to the 2-year recurrence level. In general river regulation has changed the flow regime substantially, and the Loddon River Environmental Flow Scientific Panel has been created to determine recommended flows appropriate for conservation of instream and floodplain environmental values, to be used in balance with the rights of existing users

Two Aboriginal Clan groups inhabit the lower Loddon River region – the Barapa Barapa from Boort to Kerang, and the Wamba Wamba from Kerang to the River Murray (NCCMA, 2000).

Within the study area, there are indigenous sites of cultural significance. For example, within the Gunbower and Kerang regions there are hundreds of registered indigenous sites of archaeological significance (Parks Victoria 2003), such as scar trees, mounds, middens, burial sites, and hearths, and many more are likely to be uncovered. Management of the Aboriginal cultural heritage is facilitated by liaison with the North West Nations Clans Aboriginal Corporation and the North West Region Aboriginal Cultural Heritage Program.

The rivers and tributaries in the Lower Loddon region are often surrounded by remnant River Red Gum, Grey Box and Black Box, and occasional isolated remnant grassy woodlands and native grasslands. The central catchment tends to be dominated by Box-Ironbark forest and the associated vegetation.

A number of areas in the lower catchment have a high biodiversity and conservation value. The Kerang Wetlands and Gunbower Forest are Ramsar sites, with international significance. Wetlands of national importance include Kow, Tang Tang, Woolshed and Creswick Swamps. There are also a range of parks within the area of regional or national importance, such as Terrick Terrick, Whipstick, Kamarooka and Kooyoora State Parks. Wildlife which are valued by the local community include native fish (e.g. Golden Perch, Murray Cod and Murray Hardyhead), birds (e.g. Grey Crowned Babbler, Ramsar migratory species), reptiles (Carpet Python, Bearded Dragon), amphibians (e.g. Spotted Marsh Frog, Growling Grass Frog) and mammals (e.g. Fat-tailed Dunnart). A number of flora and fauna native to the region are considered threatened under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*, and several bird species listed in international treaties have been recorded locally.

Areas such as Gunbower Forest and Kerang Wetlands are important for recreation and tourism. Activities that occur within the region include fishing, camping, bushwalking, four wheel driving, road cycling, trail biking, orienteering, swimming, canoeing, boating, bird watching, hunting and horse riding.

Protection of natural resources (particularly water), and sustainable operation of the region as the economy develops is important to the future of the community

2.2 Ecological values of the Lower Loddon catchment

A number of plans have identified environmental values (environmental assets) in the Lower Loddon catchment and activities that are threatened these values. These include the North

Central Regional Catchment Strategy (NCRCS), North Central River Health Strategy (NCRHS), Loddon Murray Land and Water Management Strategy, the Bulk Water Entitlement (BE) conversion process, the Kerang-Swan Hill Future Land Use Pilot Project, and the Kerang and Gunbower Forest Ramsar Site Strategic Management Plans.

These environmental assets include:

- internationally significant Ramsar listed sites (e.g. Gunbower Forest and Kerang wetlands),
- nationally significant wetlands (e.g. Tang Tang and Kow Swamps),
- threatened flora and fauna species (e.g. Murray cod, Golden perch, the Great Egret),
- rivers, streams and their floodplains,
- biodiversity,
- native fish, macroinvertebrates, riparian vegetation,
- in-stream habitat, vegetation and structure.

The key threats identified through these plans include: flow deviation; poor water quality; stock access; degraded riparian vegetation; barriers to fish passage (weirs); degraded in-stream habitat; dryland salinity; urban impacts; upstream erosion; **c**hannel modification; recreation; pollution; pest plants.

As noted above, during the Problem Formulation phase, stakeholders identified two ecological values potentially at risk to be the focus of a quantitative risk analysis. These were the *ecological health of the Lower Loddon River* and *farmland ecological values*. This report discusses the development of a Bayesian decision network (BDN) model to predict the *abundance of grey-crowned babbler populations* as an indicator of *farmland ecological values* in the Lower Loddon catchment. Details of the Problem Formulation phase may be found in Westbury et al., 2005b.

3. Ecological risk assessment

3.1 General

ERA is particularly useful for assessing the effects of multiple hazards (or stressors) to a range of ecosystem components, including native flora and fauna, processes and services, while also taking account of the inherent variability and complexity of these systems.

Ecological risk is defined as the product of the *likelihood* (or *probability*) of a detrimental ecological event occurring and the *consequences* that arise if that event occurs. Thus, a risk assessment requires that the important environmental/ecological values be clearly identified along with all the hazards that could potentially adversely affect these values.

The key steps involved in a risk assessment are (AS/NZS, 2004; Hart et al., 2005):

- *Defining the problem* – this involves careful scoping of the problem, agreement on how it is to be assessed, and how the acceptability of actions will be judged.
- *Deciding on the important ecological values and hazards and threats to these values* – hazards are evaluated and priorities set by evaluating effects on valued elements of ecosystems and ecosystem services.
- *Analysing the risks to the ecological values* – the analysis process used needs to be appropriate for the situation in order to provide adequate information for decision-making. Guidance is provided on both qualitative and quantitative methods.
- *Characterise the risks* - the technical details of risk analyses needs to be made accessible to decision-makers and broader stakeholders. In particular, the uncertainties and assumptions associated with analyses require careful and transparent documentation.
- *Making decisions* – selection of the best management option or strategy will be the one that results in the effective minimisation of the ecological risks, while also being cost-effective and acceptable to the stakeholders. Guidance is provided on a number of multi-criteria methods for assisting this process.
- *Managing the risks* – a risk management plan provides recommendations on managing or mitigating all high or unacceptable risks. The risk management plan should include a robust program to *monitor progress* to ensure the strategies are working, and a *review and feedback process* for making changes if needed.

Figure 3 is a flow diagram of the risk assessment and management framework. The key point of this framework is that the process should be *iterative*, allowing new information to be incorporated into the risk management plan as it becomes available. This is the essence of an adaptive management process.

3.2 Problem formulation

The first stage of an ecological risk assessments (ERA) is the Problem Formulation phase. This generally involves three steps:

- Defining the problem and the scope of the assessment,
- Deciding on the important ecological values and hazards and threats to these values,
- Undertaking a qualitative analysing the risks to the ecological values.

In successful ecological risk assessments, the problem formulation is done in close collaboration with all relevant and interested stakeholders. This ensures that the issues investigated and the outcomes of the assessment are useful and appropriate for local management needs.

The focus for the Lower Loddon ERA and the type of management information needed was identified with input from a range of local stakeholders with an interest in the catchment. This was achieved through stakeholder workshops, phone and one-on-one interviews, meetings and local tours with resource managers and community members and information gathered from regional management strategies, plans and investigations. The stakeholder group involved in the project have considerable knowledge and experience in catchment management of the lower Loddon Region. A list of the local stakeholders involved in the risk assessment is given in Table 1.

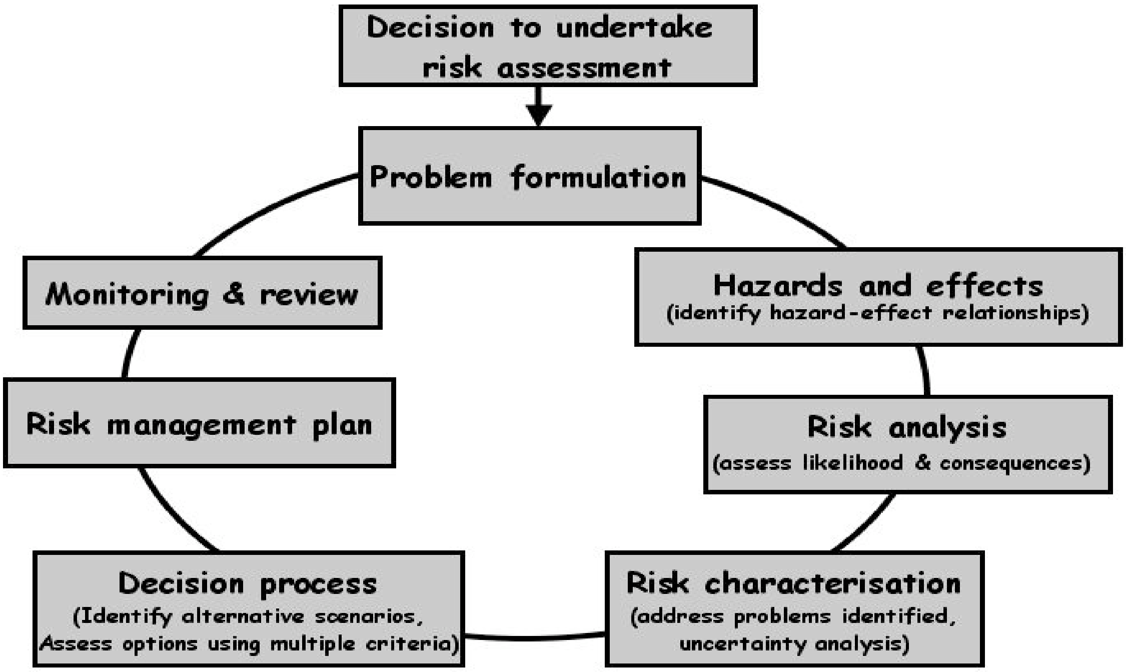

Figure 3: Overall risk assessment and management framework

3.2.1 Stakeholder consultation in the Problem Formulation phase

Initial discussions were held with the North Central Catchment Management Authority (NCCMA - Tim Shanahan) and Goulburn-Murray Water (G-MW - Anne Graesser) project representatives. The local information they provided was invaluable for identifying the relevant stakeholders and how the consultation would be best targeted. A stakeholder mapping exercise was conducted with them before making direct contact with the local resource managers and community members.

Stakeholders were initially contacted by phone to inform them about the project and ascertain their willingness to be involved. A follow-up project fact sheet was sent to all interested stakeholders. The first stakeholder workshop was held on the 26th November 2004. There were 32 participants from a range of agencies and the community. For those who wanted to contribute but could not make the first stakeholder workshop, personal interviews were conducted and their input incorporated and reflected in the wider stakeholder consultation.

A number of stakeholder regional planning processes in the Lower Loddon catchment have already identified ecological values of high management priority. These include the North Central Regional Catchment Strategy (NCRCS), North Central River Health Strategy (NCRHS), Loddon Murray Land and Water Management Strategy, the Bulk Water Entitlement (BE) conversion process and the Kerang-Swan Hill Future Land Use Pilot Project.

A list of the values from these previous processes was compiled and presented to the stakeholders for comment, clarification and possible expansion. Using this compiled list as a basis for further discussion meant that stakeholders who had been involved in previous projects did not feel the risk assessors were starting from scratch and had taken notice of the substantial information gathered from previous work. Stakeholders added to this list, discussed the values identified, and selected the ecological values on which to conduct risk assessments. These were the (a) *ecological health of the Lower Loddon River,* and (b) *farmland ecological values.*

Stakeholders then discussed threats and hazards to the two key values. In a similar way to the value identification exercise, a list of the threats identified from previous processes was compiled and workshop participants added to this. Using the list of threats stakeholders mapped their knowledge of threats and factors that may influence the likelihood of risks occurring to the ecological values. These discussions were summarised by stakeholders in conceptual models developed in groups of 4 to 6 people. Stakeholders also identified that it was important for the risk assessment to incorporate and build on the useful work and projects undertaken in the catchment to date, and link this project directly to on ground management actions.

After the first stakeholder workshop, a meeting was held with key stakeholder representatives (G-MW, NCCMA, community members) to establish the assessment and measurement endpoints. The meeting included two community members to ensure the views of the community were taken into account and that the broader community felt that agency staff were not solely making the crucial decisions. Background information and a summary table of suggested endpoints and the strengths and weaknesses of each were presented to assist in the decision-making.

Following this key stakeholder representative meeting, feedback in the form of a newsletter was provided to all stakeholders. This outlined the outcomes of the problem formulation phase, including outcomes of the stakeholder workshop and key stakeholder representatives meeting.

3.2.2 Stakeholder consultation in the Risk Analysis phase

The both Bayesian Network structures developed by the risk assessor, with considerable input from experts on the grey-crowned babbler (*Pomatostomus temporalis*), was reviewed by a broad group of stakeholders at a workshop held in April 2005. The workshop was attended by 14 stakeholders including natural resource managers (NCCMA, DPI, G-MW) and local landowners. Prior to the workshop, fact sheets on Bayesian Networks and the Lower Loddon River Network were sent to workshop participants to provide background information.

At the workshop specific feedback was gathered on whether the network:

- realistically represented the Lower Loddon system;

- assessed the interactions between key threats impacting the grey-crown babbler populations and management actions to deal with these; and
- provided information to assist in answering key catchment management questions.

At the workshop stakeholders discussed and provided input on the key management information needs from the modelling, and alterations/improvements required in the network structure. Written feedback from the second stakeholder workshop was circulated to all stakeholders, including updates to the networks.

The quantification of the Bayesian Network CPTs was done in consultation with ecological and local experts and is detailed for the individual CPTs in Appendix A.

3.2.3 Consultation on project outcomes

A stakeholder information session was held on 12 August 2005, which presented and discussed the results of the risk assessment and information from the Bayesian networks. The workshop was attended by 16 stakeholders, including natural resource managers (NCCMA, DPI, G-MW) and local landowners. At the workshop, stakeholders expressed support for the Bayesian networks, and urged that they be used by Loddon catchment resource managers (NCCMA, G-MW, DPI, landowners).

Methods for incorporating the Bayesian network into local resource management processes were identified by stakeholders and included: nominating key people to receive extensive technical documentation, catchment decision-making processes to be targeted (e.g. Loddon Implementation Committees, Stressed Rivers Project), the need for an additional 'farmer friendly flyer', and involvement of local resource managers in further monitoring identified for the Bayesian network.

Written feedback on the project was also sought from stakeholders on the day. Some 95% of participants thought the risk assessment was good to very good in improving understanding of catchment risks and knowledge gaps, and providing information for assisting management of the Lower Loddon River.

Table 1: Lower Loddon ERA stakeholder participants

Representation	Participants
North Central Catchment Management Authority	Jo Haw, Rohan Hogan, Angela Gladman, Jon Leevers, Tim Shanahan.
Goulburn-Murray Water	David Douglas, Anne Graesser, Lester Haw, Dale McGraw, Ross Stanton, Daniel Irwin.
Landowner from: Loddon/Campaspe Irrigation Implementation Committee, Torrumbarry Water Services Committee, Loddon Murray Forum, Boort Western Loddon Salinity Management Plan Committee, Kerang-Swan Hill Future Land Use Pilot Project, Victorian Field and Game.	Stan Archard, Barry Barnes, John Baulch, Brian Drummond, Neville Goulding, Paul Haw, Bradley Haw, Ken Hooper, Tom Lowe, Colin Myers, John McNeil, Stuart Simms, Rod Stringer, Bill Twigg, Geoff Williams, Anne Teese.
Department of Primary Industries	Rob O'Brien, Matt Hawkins
Environment Protection Authority, Victoria	Dean Edwards, John Williamson.
Parks Victoria	Bruce Wehrner
Lower Murray Water	Kate Maddy
Loddon Shire	Trevor Barker
Gannawarra Shire	Des Bilske

4. Development of the Bayesian decision network model for farmland ecological values

4.1 Overview

Resulting from stakeholder consultations, it was decided to use abundance of grey-crowned babbler (*Pomatostomus temporalis*) populations as the indicator of farmland ecological value. This bird is relatively common in the region, is omnivorous, sedentary and relatively easy to monitor. It will also be part of future monitoring programs in the Loddon catchment.

Other measurement endpoint considered were: crested shrike-tit, carpet python and tree goanna. These species would all be suitable measurement endpoints as they are: direct biological measure of importance to the local ecosystem; reasonably widespread through the region of interest; of interest to the stakeholders; intended for use in management of the region under the BAP; and susceptible to the threats and hazards to habitat in the region.

The three main tasks in developing a Bayesian decision network model to predict the abundance of grey-crowned babbler (*Pomatostomus temporalis*) populations are:

- construction of the graphical structure,
- population of the node states and the conditional probability tables (CPT's) using data or expert opinion,
- testing of the sensitivity and validation of the model outputs.

Developing the graphical structure involves the formal and systematic identification of the system variables and the interactions (linkages) between them. In almost all cases, the initial network is overly complicated and well-founded decisions need to be made on what variables to omit from the network.

For the grey-crowned babbler Bayesian decision network model, the key variables and the nature of their dependencies were identified and refined through:

- the stakeholder workshop process, where a conceptual model was constructed and key hazards and threats were identified,
- a comprehensive survey of the relevant literature,
- consultations with experts in grey-crowned babbler ecology.

Since the main purpose of this model was the prediction of abundance of grey-crowned babbler populations to inform management decisions, it was important that the model should not be overly detailed (Reckhow, 1999). The guiding principle therefore was to include only those variables and relationships, which contribute to the ability to predict ecosystem attributes of management relevance (Borsuk *et al.*, 2004). Each node in drafts of the graphical Bayesian network model was systematically reviewed to determine if the variable it represented was either (a) controllable, (b) predictable, or (c) observable at the scale of the management problem.

To formalize the graphical model as a Bayesian network model, variables had to be clearly defined, be observable and testable. The definition of model variables, the states included and the placement of break-points (in the case of continuous variables) was established using the relevant literature and in consultation with technical experts.

Probabilities for CPTs of the various model variables were specified using a combination of empirical data, functional relationships and expert judgements.

The Bayesian decision network modelling was carried out using the software Netica (Norsys Software Corp. 1997-2003). Netica uses junction tree algorithms to perform probabilistic inference (Norsys, 1997). Details on computation and algorithms used in Netica are available in Neapolitan (1990) and Spiegelhalter *et al.* (1993).

4.2 Graphical structure of the network

As noted in the previous section, the Bayesian decision network model developed predicts the abundance of grey-crowned babbler (*Pomatostomus temporalis*) populations as the indicator of farmland ecological value. This common bird species has been well studied in eastern Australia, from southern Queensland through northern Victoria (Brown et al., 1982; MacNally, 2000).

The Bayesian network structure was based on the conceptual model initially developed during the first stakeholder workshop (Figure 4), and on information in catchment reports and the scientific literature. The Bayesian network structure was reviewed by a broader group of stakeholders at a workshop held in April 2005, which included local resource managers (DPI, NCCMA, G-MW) and landowners.

The full graphical Bayesian probability network for grey-crowned babbler abundance in the Lower Loddon catchment is shown in Figure 5 and a summary of the network variable definitions, metrics and states is given in Table 2.

The network structure (Figure 5) represents the key cause-effect relationships determining grey-crowned babbler abundance in the Lower Loddon catchment. These are more fully discussed in Appendix A, and can be summarised into the following categories:

- *Habitat availability* –the quantity and quality of habitat (both overstorey and understorey vegetation) is important for grey-crowned babbler, primarily for protection from competition and predation. Grazing is the most significant influence on habitat quality.
- *Food availability* – the important sources of food for grey-crowned babbler in the lower Loddon River are invertebrates and vegetable matter such as fruit and seeds.
- *Biological factors* – these include competition from the noisy minor (*Manorina temporalis*), predators (e.g. feral cats) and reproduction.

The initial Bayesian structure included additional variables (Figure 4), but these have been omitted from the current BDN, as the data, information and understanding required to adequately include them is currently not available. And given the very high uncertainty surrounding these variables, it would not be possible to generate any meaningful information from the network with their inclusion. Information on these variables and their relationships have been included in Table 2 and Appendix A, to provide a starting point for their future inclusion when more information and data allows.

4.3 Population of the variables and the conditional probability tables

The states of the variables and the conditional probability tables (CPT) were populated using information from catchment reports and studies, the scientific literature, assessment of catchment data and expert opinion from ecologists. The information and data sources for each node are summarized in Table 2. Full details are provided in Appendix A.

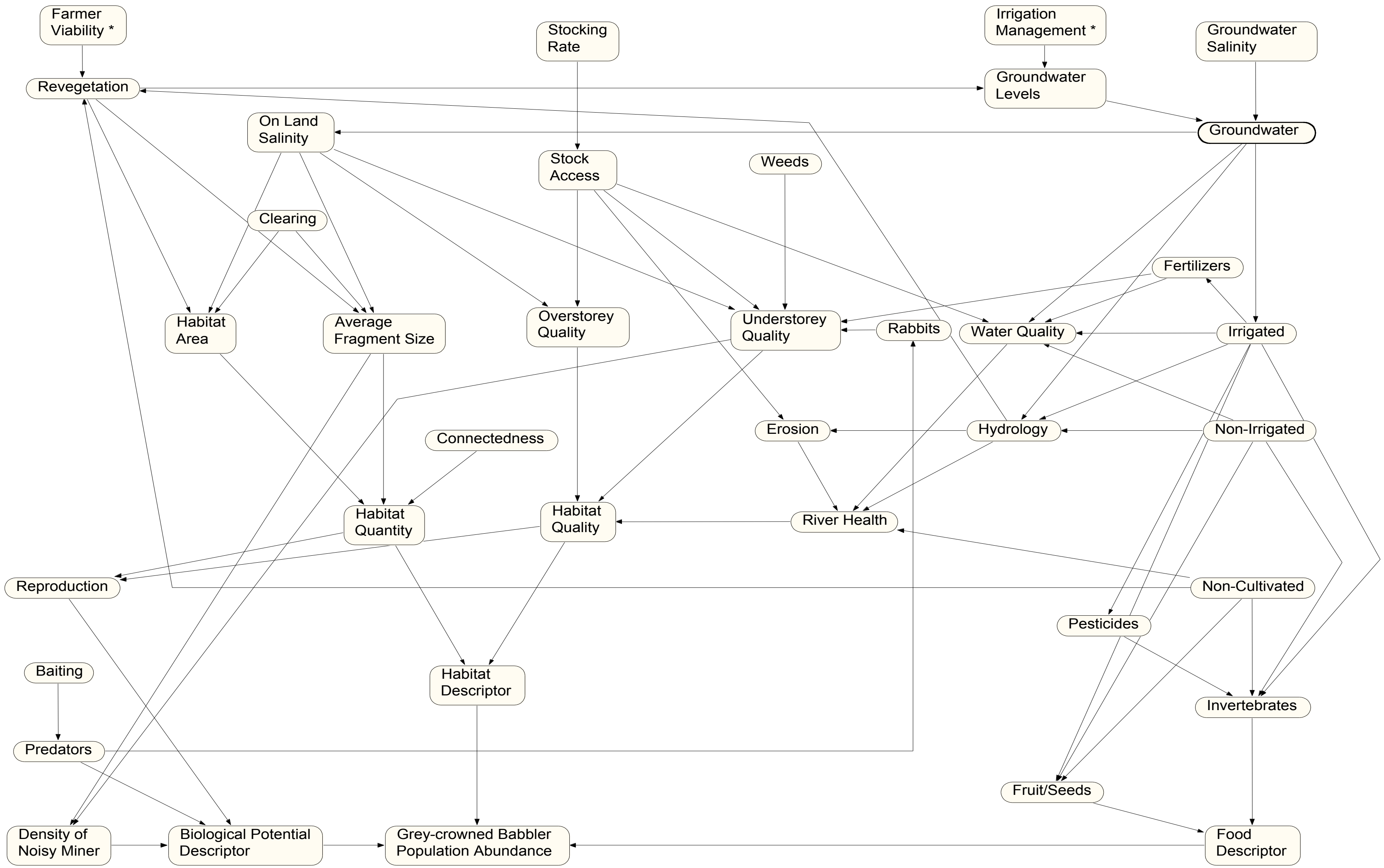

Figure 4: Conceptual model of factors controlling the abundance of grey-crowned babbler populations

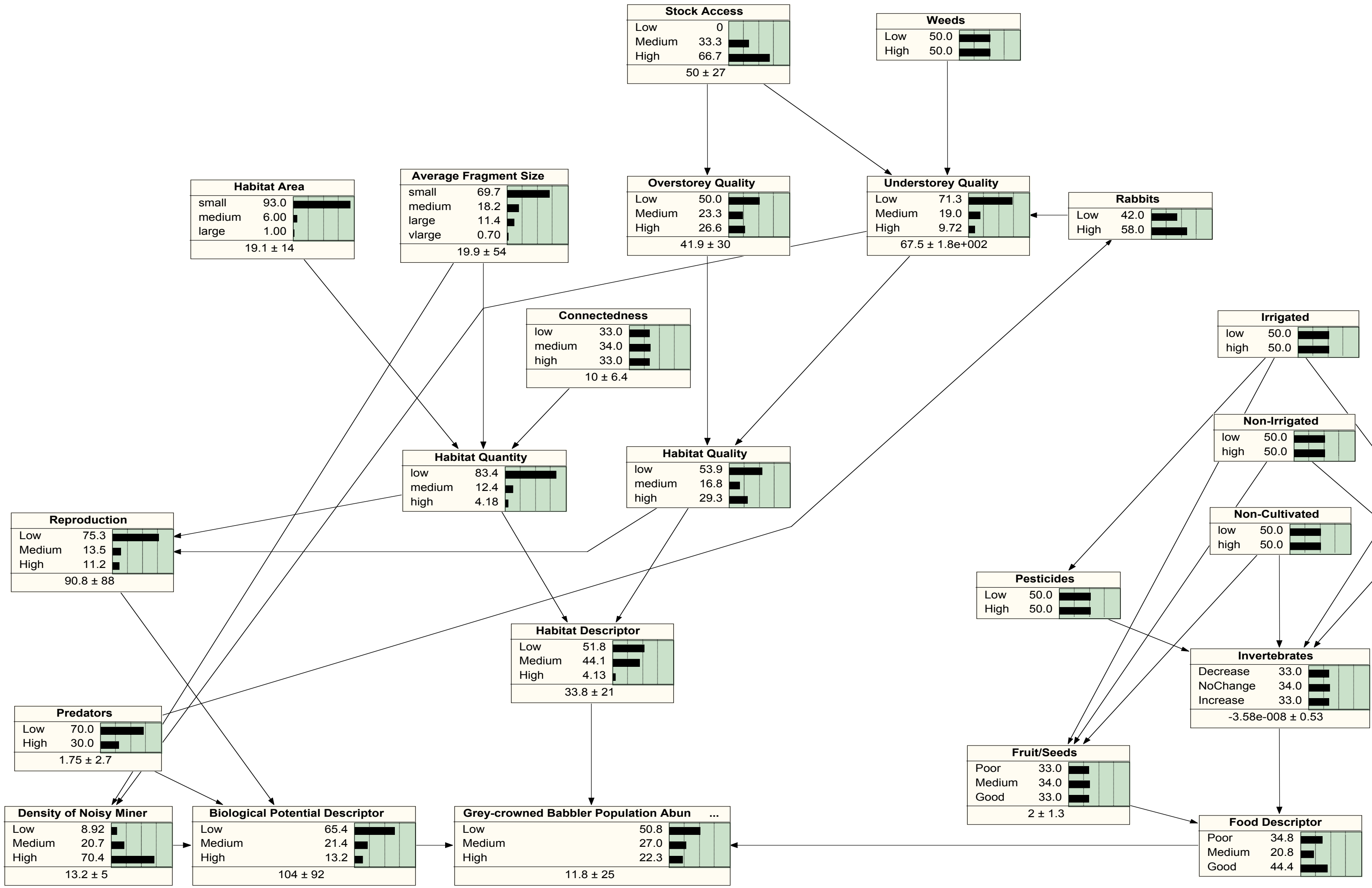

Figure 5: Bayesian Network for grey-crowned babbler abundance in the Lower Loddon catchment (current conditions)

Table 2: Summary of the variables used in the Lower Loddon grey-crowned babbler Bayesian decision network model

Variable and description	States	Rationale/purpose of variable	Parents	Source[1]
Average Fragment Size [ha]	small <10 ha medium 10-50 ha large 50-100 ha vlarge >100	Habitat fragment size is a key variable in woodland bird presence/absence. Affects the measurement endpoint directly as well as via competition. States determined from previous studies (see "Source" column).	Clearing On-land Salinity Revegetation	McNally et al 2000a, Major et al 2001, 2001 GIS data. Also Andren 1994, Fahrig 1997.
Baiting [a] [N/A]	Present Absent	Baiting controls 85-95% of the main predators of concern. Assumes effective baiting strategies as described in the cited studies.	-	Hutchings et al 1998, Thomson et al 2000, Short et al 1997.
Biological Potential Descriptor [N/A]	Low Medium High	Intermediate node – i.e. synthetic variable characterizing biological effects	Reproduction Predators Competition	Synthetic variable, so process knowledge, analyst judgement required.
Bird Population Abundance - Grey-crowned Babbler [birds/10 ha]	Low < 2 Medium 2-8 High > 8	Measurement endpoint for network. Is one possible representative of ecological value in the region. States determined from previous studies.	Habitat Descriptor Food Descriptor Biological Potential Descriptor	McNally et al. 2000, Dow and King 1984, Lockwood and Robinson 1997, Brown et al. 1983.
Clearing [a]	Low High	Affects area of habitat available, note most clearing has already occurred, so node not essential in current network.	-	-
Connectivity [no. connections/fragment]	Low < 2 Medium 2-8 High > 8	A measure of how connected different habitat areas are. States determined from previous studies.	-	Major et al. 2001, MacNally et al 2000, 2001 GIS data.
Competition/Density of Noisy Miner [birds/ha]	Low < 5 Medium 5-12 High > 12	States determined from previous studies of impact of competition via removal tests.	Understorey Quality Average Fragment Size	Grey et al 1997, Grey et al. 1998. Also Major et al. 2001, MacNally et al. 2000.
Erosion [a]	-	Not included in current network.	Hydrology Stock Access	-
Farmer Viability [a]	Viable Non-viable	Affects revegetation efforts. Lack of data and specific studies of this factor mean uncertainty is too high to be useable in current network.	-	-
Fertilizers [a]	Present Absent	-	Irrigated Non-irrigated	-

Variable and description	States	Rationale/purpose of variable	Parents	Source[1]
Food Descriptor [N/A]	Poor Medium Good	Intermediate node – i.e. synthetic variable characterizing food availability	Fruit/seeds Invertebrates	Synthetic variable, so process knowledge, analyst judgement required.
Fruit/Seeds [-]	Poor Medium Good	Secondary food source for endpoint. States defined from previous studies.	Irrigated Non-irrigated Non-cultivated	Recher 1996, Chamberlain and Fuller 2000
Groundwater [N/A]	Poor Good	Intermediate node – i.e. synthetic variable characterizing groundwater quality in terms of both groundwater level and salinity. Uncertainty too high to be useable in current network.	Groundwater Levels Groundwater Salinity	Synthetic variable, so process knowledge, analyst judgement required, Sinclair Knight Merz 2000
Groundwater Levels [a] [m]	Shallow < 1m Deep > 1m	Affects land use and on-land salinity. States determined from Report on Groundwater 2000.	Irrigation Management	Sinclair Knight Merz 2000
Groundwater Salinity [EC]	Low < 55000 High > 55000	Affects on-land salinity	-	Sinclair Knight Merz 2000, NCCMA 2004
Habitat Area [%]	Low < 5 Medium 5-10 High > 10	Total habitat area available.	-	Andren 1994, Fahrig 1997, 2001 GIS data
Habitat Descriptor [N/A]	Poor Medium Good	Intermediate node – i.e. synthetic variable characterizing habitat quality and quantity	Habitat Quantity Habitat Quality	Synthetic variable, so process knowledge, analyst judgement required.
Habitat Quality [N/A]	Poor Medium Good	Intermediate node – i.e. synthetic variable characterizing habitat quality based on overstorey and understorey density	Overstorey Quality Understorey Quality	Synthetic variable, so process knowledge, analyst judgement required, MacNally et al. 2000
Habitat Quantity [N/A]	Poor Medium Good	Intermediate node – i.e. synthetic variable characterizing habitat quantity based on total area and fragment size	Connectivity Average Fragment Size Habitat Area	Synthetic variable, so process knowledge, analyst judgement required, MacNally et al 2000.
Hydrology [a] [N/A]	Unchanged Changed	Partly determined by previous studies (Briggs et al 1997) on the effect of hydrology on riparian vegetation. The effect on wider catchment scale vegetation requires more work.	Iriigated Landuse Non-Iriigated Landuse	Briggs et al 1997

Variable and description	States	Rationale/purpose of variable	Parents	Source[1]
Invertebrates [insects/day by suction trap]	Decrease > 20% NoChange ± 20% Increase > 20%	States based on trends in Benton et al 2002 (note, UK based).	Pesticides Habitat Descriptor Non-cultivated land	Recher 1996, Benton et al 2002[*], Franzblau and Collins 1980, Vickery et al 2001
Irrigated – amount of irrigated farmland [% area]	Low < 30 High > 30	Requires further work to define states.	-	2001 GIS data
Irrigation Management [a] [N/A]	Present Absent		-	
Non-cultivated – amount of non-cultivated land [% area]	Low < 10 High > 10	Requires further work to define states.	-	2001 GIS data
Non-irrigated – amount of non-irrigated land [% area]	Low < 45 High > 45	Requires further work to define states.	-	2001 GIS data
On-land Salinity [a] – area of land affected by salinity [dS cm^{-1}]	Low < 8.6 (= soil classes A, B, and C, ~ 4000 ppm) High > 8.6 Vhigh > 16	Affects amount of land which isn't useable for agriculture, and thus area which may be revegetated. And may also restrict this revegtated area if salinity very high. Note DPI also uses S0 (<2 dS cm^{-1}), S1 (2-4), S2 (4-8), S3 (8-16) and S4 (>16) classification.	Groundwater	Soil survey data of classes A, B, C, D as used by DPI and CMAs.
Overstorey quality [canopy cover %]	Poor < 20 Medium 20-40 Good > 40	Alternatively [trees/ha]: Poor < 30 Medium 30-100 Good > 100	Stock Access	Grey et al. 1997, Woinarski et al. 2000, Martin and Possingham 2005, Dorrough and Moxham 2005.
Pesticides [N/A]	Present Absent	Affects invertebrate food source availability. Uncertainty too high to be useable in current network.		Solomon et al. 2001
Predators [ha^{-1}]	Low < 0.5 High > 0.5	States defined from previous studies.	Baiting	Marlow et al. Thomson et al. 2000, Hutchings 1998, Short et al. 1997, Molsher et al .1999.

Variable and description	States	Rationale/purpose of variable	Parents	Source[1]
Rabbits [ha^{-1}]	Low < 2 High > 2	Affects understorey quality.	Predators	Banks et al. 1998, Molsher et al. 1999.
Reproduction	Low Medium High	More complex reproductive modelling to characterize this portion of the network may be required. E.g. based on Wiley and Rabenold 1984.	-	Ford et al 2001, Wiley and Rabenold 1984
Revegetation [a]			Farmer viability	Dorrough and Moxham 2005.
River Health [a]		Synthetic variable characterizing state of river.	Water Quality Hydrology Erosion	
Stocking Rate [a] [head/ha]	Low < 0.8 High > 0.8	States defined from previous studies.	-	James 2003, Kuhnert et al 2005
Stock Access [% reach]	Low < 10 Medium 10-30 High > 30	Currently characterizes access to riparian zones only. Requires extension to non-riparian catchment areas.		ISC data 1999, Kuhnert et al 2005, Jansen and Robertson and Rowing 2001, Martin et al 2005, Dorrough and Moxham 2005.
Understorey Quality [% cover, but also "shrubs"/ha, or height of undergrowth]	Poor < 25 % Medium 25-55 % Good > 55 %	Characterizes the structure and quality of available understorey. States determined from previous studies. Note the effect of fire on understorey structure is not currently included and may be an area for model development (Adam and Robinson 1996).	Stock Access Weeds Rabbits On-land Salinity	Luck et al. 1999, Kuhnert et al 2005, Martin and Possingham 2005, Jansen and Robertson 2001, Dorrough and Moxham 2005, Woinarski et al. 2000.
Water Quality [a] [N/A]	Poor Medium Good	Lack of data and specific studies of the effect of this factor on habitat and the measurement endpoint mean uncertainty is too high to be useable in current network. Additional specifications for water quality might be obtained with further work along the lines of Ha and Stenstrom (2003).	Stock Access Groundwater Irrigated Landuse Non-Iriigated Landuse	
Weeds [% cover]	Low <20% High >20%	This node represents the weed cover within the total habitat area. States have been defined according to previous studies.	-	Woinarski et al. 2000, Dorrough & Moxham 2005.

1. Note sources listed in order of importance. Also, analyst judgement is required where multiple sources do not agree exactly. 2. Not included in current Lower Loddon Bayesian Network due to lack of data. 3. Non-local/overseas references. Local studies used where available.

4.4 Sensitivity analysis

A sensitivity analysis was conducted on the Bayesian Network to assess the variables having the most influence on Grey-crowned Babbler population abundance being predicted as ‘low’. The results are presented in Figure 6.

The software (Netica) conducts the sensitivity analysis by systematically varying the values of the individual network variables, to determine how much the mean belief of the ‘grey-crowned babbler population abundance’ node being ‘low, can be influenced by a single finding at each variable. The results given are the range of lowest to highest that the expected values of ‘grey-crowned babbler population abundance’ can have, due to a finding at each variable (Wooldridge & Done, 2003; Norsys Software Corp., 2003).

This graph shows the relative level of influence each of the network variables, with variables at the bottom of the graph (represented with the widest bars) having the most influence, and influence decreasing as you move up through the graph (and the bar size decreases).

The grey-crowned babbler abundance is seen to be most sensitive to changes in habitat descriptor, habitat quality, reproduction, and the quality of the overstorey and understorey vegetation.

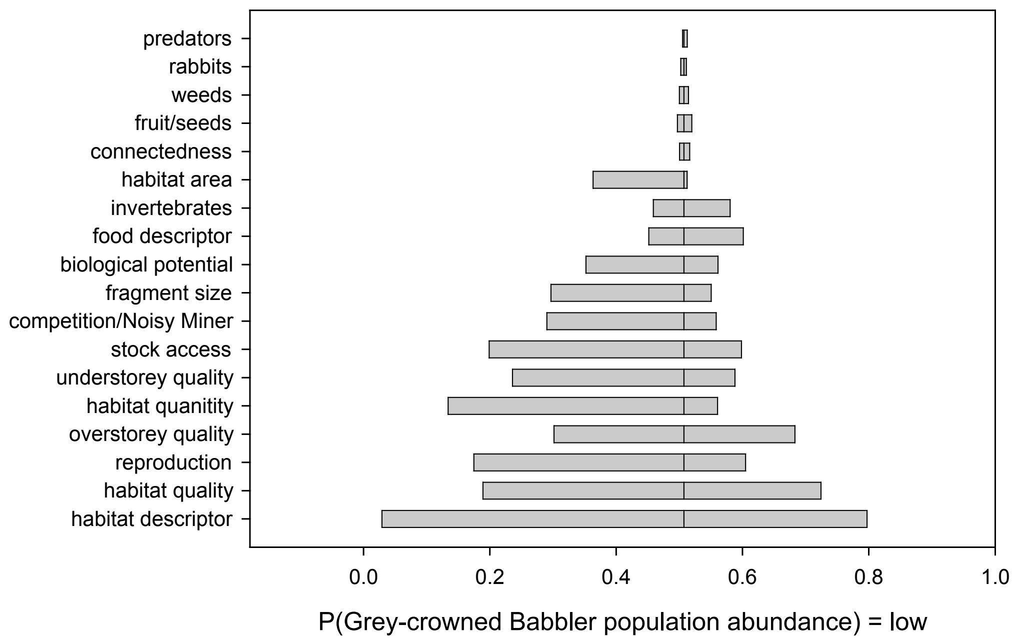

Figure 6: Sensitivity Analysis Results - the influence of network variables on “Grey-crowned Babbler Population Abundance” being in a ‘low’ state

4.5 Network predictions

Application of the Bayesian decision network model to present conditions shows a high probability of grey-crowned babbler population abundance being low (Figure 5). This appears to be driven by poor habitat, and low biological potential (as indicated in the sensitivity analysis).

The present conditions result in the habitat variables having a high probability of being in a low to medium condition, while biological potential has a high probability of being low. Although habitat quantity has a high probability of being in a 'low' state, habitat quality is less likely to be 'low'. The variables driving biological potential are more consistently negative for the biological potential descriptor.

4.6 Validation of the Bayesian network

There is currently not enough data and information available on the network variables to validate this model, and thus the predictive accuracy of the network cannot be estimated at this stage.

5. Testing of management scenario to fencing off stock access

An important application of Bayesian networks is their ability to provide information on various management scenarios. Variables in the network can be updated to reflect certain management actions, and the network run to ascertain the probabilities of improvement in the selected endpoints. In this way, various management actions can be tested for their relative effectiveness and predicted outcomes.

This section provides the results of model predictions for one important management action – fencing off stock access to the grey-crown babbler habitat.

Stock have been allowed to access most of the Lower Loddon catchment over a long period of time. Although natural resource managers (NCCMA, DPI) and landowners have recently begun major on-ground fencing works to reduce stock access to the river and its riparian zone (Rob O'Brien, pers. comm.). It is planned to continue this management action into the future.

The management scenarios tested was to increase the amount of fencing along the Lower Loddon River so that stock access was reduced. Sensitivity analysis identified stock access as having a major influence on grey-crowned babbler abundance, predominately through stock degrading habitat. Stock access was therefore considered an important management action to be assessed. Note however that stock access data is based on exclusion from riparian zones (as in the macroinvertebrate BDN – Westbury et al., 2006), as overall stock access data for non-riparian zones was not available. This would be a useful area for collection of further data.

The network was run for three levels of stock access - low, moderate and high[1]. The results are summarised in Figure 7 (full details of these model calculations are presented in Appendix A).

Reducing stock access was shown to significantly improve grey-crown babbler abundance (Figure B1 cf B2). For example, the probability that grey-crown babbler populations will be medium to high abundance improved from around 40% for high access to around 81% for low access.

These results support the current Loddon catchment management plan, where major on-ground fencing works are being implemented to reduce stock access to the riparian zone and the river channel.

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[1] Stock access is assessed as ***Low*** if stock are associated with <10% of the reach, ***Moderate access*** if stock have access to10-30% of the reach, and ***High access*** if >30% of the reach (Table 2).

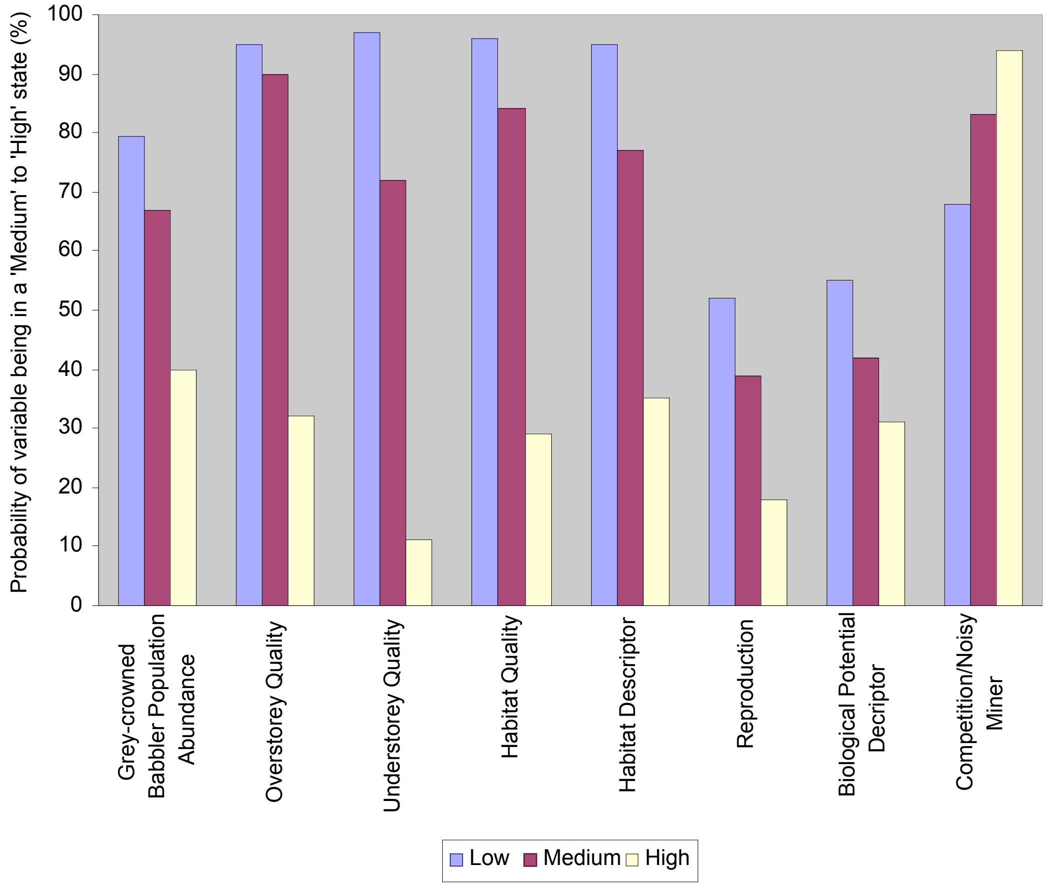

Figure 7: Probability that grey-crowned babbler populations will be medium to high abundance for three levels of fencing off stock access

6. Conclusions

The Bayesian decision network predicted that the grey-crowned babbler population abundance in the Lower Loddon catchment would be poor. The sensitivity analysis showed it is the habitat variables (e.g. in-stream habitat, food availability, in-stream vegetation, turbidity, sedimentation, riparian vegetation, woody debris and roots, bank erosion) that have the greatest influence in keeping the abundance of grey-crowned babbler populations low.

There is currently not enough data and information available to update or validate the Bayesian decision network. More data is required to reduce the uncertainty and improve the robustness of the model.

Local resource managers (NCCMA, G-MW, DPI) and landowners expressed considerable support for the grey-crowned babbler BDN model, and urged that it be used to assist decision-making in the Lower Loddon catchment.

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Appendix A: Details of the Grey-crowned babbler Bayesian decision network model

A.1 Assessment endpoint

The population abundance of the Grey-crowned Babbler (*Pomatostomus temporalis*) was chosen as the measurement endpoint for the Lower Loddon Catchment Farmland Ecological Value Bayesian Network. The bird is relatively common in the region, is omnivorous, sedentary, and relatively easy to monitor. It is also a part of future monitoring programs in the Loddon catchment.

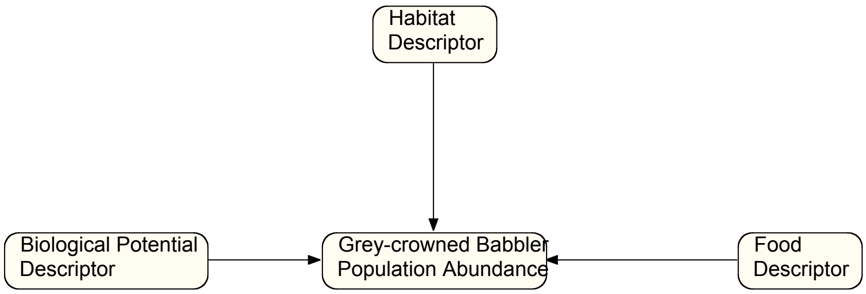

Figure 1. Graphical submodel for Grey-crowned Babbler Population Abundance

The endpoint's three states are "low", "medium" and "high", which are quantitatively defined from studies on the Grey-crowned Babbler in eastern Australia, from southern Queensland through northern Victoria (Brown et al. 1982, MacNally 2000).

The endpoint is dependent on three synthetic variables which describe the three main factors affecting population abundance, biological interactions, habitat, and food availability (Figure 1).

The literature is quite consistent in considering habitat as the most important factor (e.g. Andren 1994, Fahrig 1997, Jansen and Robertson 2001, MacNally et al. 2000, MacNally and Horrocks 2002, Martin and Possingham 2005, Kuhnert et al. 2005). Note however, that there is a significant element of analyst judgement in these conditional probabilities, as the variables being considered are 'synthetic' and are not directly physically measurable.

Table 1. Conditional Probabilities for Grey-crowned Babbler Population Abundance

			Grey-crowned Babbler Population Abundance		
Food Descriptor	**Biological Potential Descriptor**	**Habitat Descriptor**	**Low**	**Medium**	**High**
Poor	Low	Low	95	5	0
Poor	Low	Medium	30	40	30
Poor	Low	High	10	30	60
Poor	Medium	Low	85	15	0
Poor	Medium	Medium	30	30	40
Poor	Medium	High	10	30	60
Poor	High	Low	75	25	0

Poor	High	Medium	20	40	40
Poor	High	High	5	25	70
Medium	Low	Low	75	25	0
Medium	Low	Medium	20	40	40
Medium	Low	High	0	20	80
Medium	Medium	Low	70	30	0
Medium	Medium	Medium	20	40	40
Medium	Medium	High	0	20	80
Medium	High	Low	70	30	0
Medium	High	Medium	20	30	50
Medium	High	High	0	15	85
Good	Low	Low	75	25	0
Good	Low	Medium	20	30	50
Good	Low	High	0	20	80
Good	Medium	Low	70	30	0
Good	Medium	Medium	10	40	50
Good	Medium	High	0	15	85
Good	High	Low	70	30	0
Good	High	Medium	10	30	60
Good	High	High	0	10	90

A.2 Habitat Descriptor

The "Habitat Descriptor" node is a synthetic variable characterizing habitat availability and quality for the Grey-crowned Babbler. Three states were defined: "low", "medium" and "high". This is dependent on the basis of the given states for "Habitat Quantity" and "Habitat Quality", which are equally weighted. A more detailed description of the habitat components is given in sections A2.1 and A2.1.

A2.1 Habitat Quantity

The area of habitat available is a key variable. Both total area (Lockwood and Robinson 1997, Andren 1994) and the size of habitat fragments (MacNally and Horrocks 2002, MacNally and Bennett 1997, Seaone et al. 2004) have a significant influence bird population abundance. Additionally, the "Connectedness" of the fragments, e.g. via riparian zones or wildlife corridors which run between fragments, is a significant factor, particularly when fragments are small.

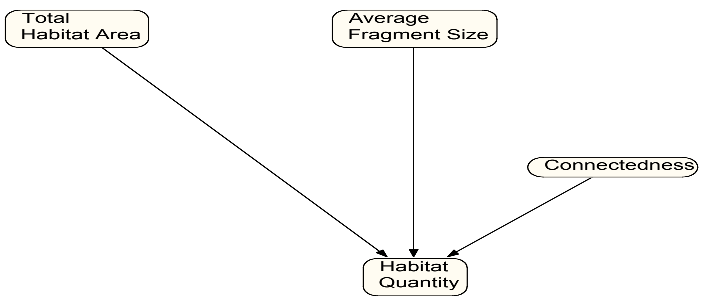

Figure 2. Graphical submodel for Habitat Quantity.

Table 2. Conditional Probabilities for Habitat Quantity.

			Habitat Quantity		
Average Fragm Size	**Total Habita Area**	**Connectednes**	**Low**	**Medium**	**Good**
Small	Small	Low	100	0	0
Small	Small	Medium	95	5	0
Small	Small	High	95	5	0
Small	Medium	Low	90	10	0
Small	Medium	Medium	90	10	0
Small	Medium	High	85	10	5
Small	Large	Low	90	10	0
Small	Large	Medium	50	30	20
Small	Large	High	30	40	30
Medium	Small	Low	70	30	0
Medium	Small	Medium	70	30	0
Medium	Small	High	70	20	10
Medium	Medium	Low	30	70	0
Medium	Medium	Medium	20	60	20
Medium	Medium	High	30	40	30
Medium	Large	Low	30	50	20
Medium	Large	Medium	20	40	40
Medium	Large	High	20	30	50
Large	Small	Low	40	40	20
Large	Small	Medium	40	40	20
Large	Small	High	40	30	30
Large	Medium	Low	10	40	50
Large	Medium	Medium	10	40	50
Large	Medium	High	10	20	70
Large	Large	Low	5	20	75
Large	Large	Medium	0	15	85
Large	Large	High	0	15	85
Vlarge	Small	Low	30	40	30
Vlarge	Small	Medium	30	40	30
Vlarge	Small	High	30	40	30
Vlarge	Medium	Low	0	10	90
Vlarge	Medium	Medium	0	10	90
Vlarge	Medium	High	0	10	90
Vlarge	Large	Low	0	5	95
Vlarge	Large	Medium	0	5	95
Vlarge	Large	High	0	0	100

A2.2 Habitat Quality

The importance of both overstorey and understorey quality on bird abundance has been examined by MacNally et al. (2000) and Ford et al. (2001). A primary effect appears to be via protection from competition and predation (Grey et al. 1997, Ford et al. 2001).

Grazing is the most significant influence on habitat quality, and this has been examined in some detail (Dorrough and Moxham 2005, Martin and Possingham 2005).

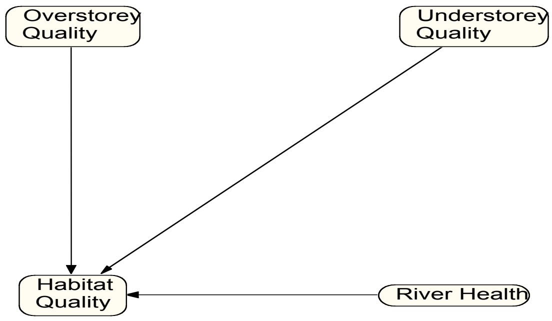

Figure 3. Graphical submodel for Habitat Quality.

Table 3. Conditional Probabilities for Habitat Quality.

			Habitat Quality		
Overstorey Quality	**Understorey Quality**	**River Health**	**Low**	**Medium**	**High**
Low	Low	Low	100	0	0
Low	Low	Medium	100	0	0
Low	Low	High	100	0	0
Low	Medium	Low	20	30	50
Low	Medium	Medium	20	30	50
Low	Medium	High	20	30	50
Low	High	Low	30	40	30
Low	High	Medium	30	40	30
Low	High	High	30	40	30
Medium	Low	Low	25	25	50
Medium	Low	Medium	25	25	50
Medium	Low	High	25	25	50
Medium	Medium	Low	20	60	20
Medium	Medium	Medium	20	60	20
Medium	Medium	High	20	60	20
Medium	High	Low	10	30	60
Medium	High	Medium	10	30	60
Medium	High	High	10	30	60
High	Low	Low	20	30	50
High	Low	Medium	20	30	50
High	Low	High	20	30	50
High	Medium	Low	10	40	50
High	Medium	Medium	10	40	50

High	Medium	High	10	40	50
High	High	Low	0	0	100
High	High	Medium	0	0	100
High	High	High	0	0	100

A2.3 Understorey and Overstorey Quality

Degradation of the quality of habitat has been indicated as a primary factor in native bird decline (Ford et al. 2001). Quality of habitat is often measured in terms of percentage cover by canopy or undergrowth (Woinarski et al. 2000, Luck et al. 1999), or by the density of trees or shrubs (Grey et al 1997, MacNally and Horrocks 2002). Grazing and thus stock access has been found to be a primary factor in habitat degradation (Kuhnert et al. 2005). Although on-land salinity is a significant worry to stakeholders, native vegetation (e.g. Black Box (*Eucalyptus largiflorens*) communities) generally appears to tolerate relatively high soil salinities (DPI 2002).

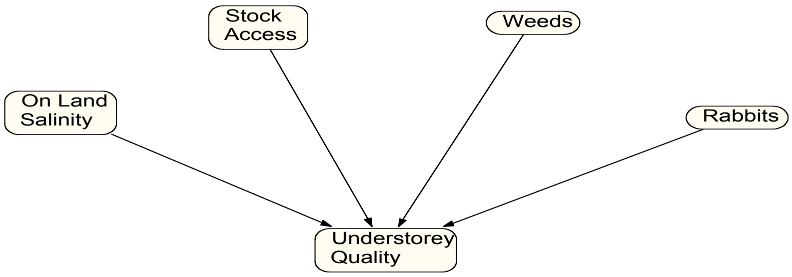

Figure 4. Graphical submodel for "Understorey quality".

There is a relatively high uncertainty associated with the role of weeds and rabbits in understorey quality, although they may generally be regarded as primarily influential for groundcover rather than what is typically defined as understorey (Martin and Possingham 2005, Woinarski et al. 2000).

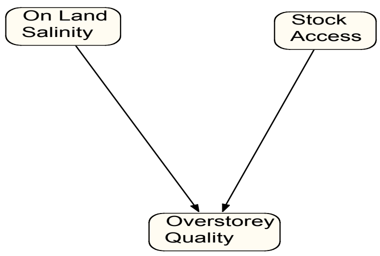

Figure 5. Graphical submodel for "Overstorey Quality."

A3 Food Descriptor

The "Food Descriptor" node is a synthetic variable characterizing food availability for the grey-crowned babbler. Three states were defined for the "food descriptor": poor, medium and good. This is dependent on the basis of given states of "Invertebrates" and "Fruit /Seeds"

(Figure 6, for states see Table 2) Invertebrates are the primary food source, and vegetable matter such as fruit and seeds are a secondary source (Adam and Robinson 1996).

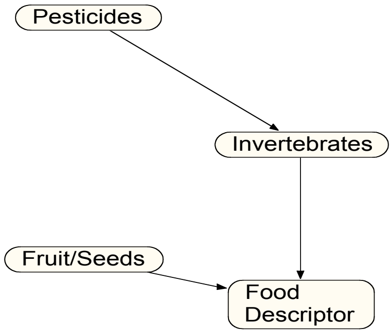

Figure 6. Graphical submodel for "Food Descriptor"

In this restricted submodel, the quantity of the available food sources is regarded as significantly more important than the quality due to its greater variability. Although there is an impact by invertebrates on the availability of fruit/seeds, this is relatively small in comparison to the fruit/seeds available.

Table 4. Conditional Probabilitiesfor Food Descriptor (pesticides not included)

		Food Descriptor		
Invertebrates	**Fruit/Seeds**	**Poor**	**Medium**	**Good**
Poor	Poor	95	5	0
Poor	Medium	85	10	5
Poor	Good	75	15	10
Medium	Poor	30	40	30
Medium	Medium	10	50	0
Medium	Good	10	30	60
Good	Poor	5	15	80
Good	Medium	5	10	85
Good	Good	0	10	90

There is little data available on required quantities of food sources on the babbler (Recher et al 1996), or the effect of incidental pesticides on the overall invertebrate population (Solomon et al 2001). As the preferred food source, invertebrates have a proportionally greater effect on the food descriptor. There is considerable scope for research to improve the conditional probability estimates in this sub-network. However, studies indicate that this part of the model may have a minimal effect on bird abundance (MacNally and Horrocks 2002), and study efforts may be better directed elsewhere.

A.4 Biological Interactions Descriptor

The "Biological Potential Descriptor" node is a synthetic variable characterizing the important biological interactions for the Grey-crowned Babbler. These interactions are "Competition

(Noisy Miner)", "Predators" and "Reproduction" (Figure 7). Three states were defined for the "Biological Potential Descriptor": low, medium and high.

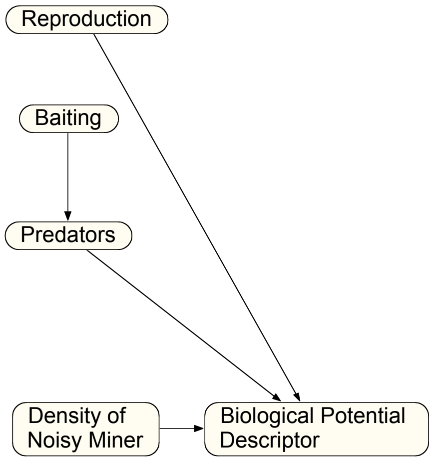

Figure 7. Graphical submodel for "Biological Potential Descriptor"

Previous studies (Grey et al. 1997, MacNally et al 2000, Major et al 2001) are consistent in finding that the primary determinant in this subnetwork is competition from the Noisy Miner (*Manorina temporalis*). Quantitative empirical experiments (removal studies) have been used to characterize the effect of this factor on native bird populations (Grey et al. 1997, Grey et al. 1998, McNally 2000), and also provide a high certainty for this effect.

However, there is a lack of quantitative data on the effect of predation and reproduction on population abundance, and subsequent low uncertainty in the influence of these factors.

Baiting programs have been shown to result in an 85-95% reduction in fox population (Hutchings 1998, Thompson et al. 2000). Certainty of fox control by baiting is high relative to control of feral cats, on which there is less data (Short et al. 1997). Anecdotal evidence suggests foxes may be a problem in the area. However, there is generally a lack of predator population data.

Reproduction (Ford et al. 2001, Major et al. 2001) is also poorly characterized, and there is high uncertainty associated with this factor. There has been some complex modelling in this area (e.g. Wiley and Rabenold 1984) which may improve this section of the network, if deemed necessary by the sensitivity analysis and/or scenario modelling.

Table 5. Conditional Probabilities for Biological Potential Descriptor

			Biological Potential Descriptor		
Reproduction	**Predators**	**Competition**	**Poor**	**Medium**	**Good**
Low	Low	Low	20	50	30
Low	Low	Medium	40	40	20
Low	Low	High	75	15	10
Low	High	Low	40	50	10
Low	High	Medium	60	30	10
Low	High	High	90	10	0
Medium	Low	Low	*10*	*30*	*60*

Medium	Low	Medium	*30*	*40*	*30*
Medium	Low	High	*70*	*20*	*10*
Medium	High	Low	*30*	*50*	*20*
Medium	High	Medium	*50*	*30*	*20*
Medium	High	High	*85*	*15*	*0*
High	Low	Low	10	20	70
High	Low	Medium	*30*	*40*	*30*
High	Low	High	*60*	*20*	*20*
High	High	Low	*20*	*30*	*50*
High	High	Medium	*50*	*30*	*20*
High	High	High	*80*	*15*	*5*

A.5 Density of Noisy Miner/Competition

Quite well characterized, the “Competition/Density of Noisy Miner” variable is dependent on “Average Fragment Size” and “Understorey Quality” (Grey et al. 1997).

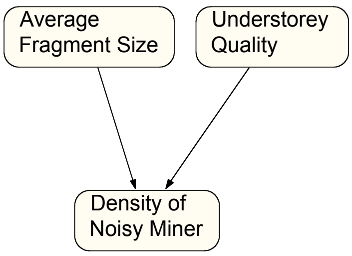

Figure 8. Graphical submodel for "Competition/Noisy Miner".

Table 6. Conditional Probabilities for "Competition/Noisy Miner".

		Competition/Noisy Miner		
Average Fragment Size	**Understorey Quality**	**Low**	**Medium**	**Good**
Small	Low	0	10	90
Small	Medium	0	30	70
Small	High	20	40	40
Medium	Low	10	30	60
Medium	Medium	30	40	30
Medium	High	50	30	20
Large	Low	20	30	50
Large	Medium	70	20	10
Large	High	80	15	5
Vlarge	Low	30	40	30
Vlarge	Medium	75	20	5
Vlarge	High	90	10	0

A6 River Health

The effect of river health on the measurement endpoint is primarily via its influence on habitat (Briggs et al. 1997). There is high uncertainty associated with this sub-network, and it is not included in the current model.

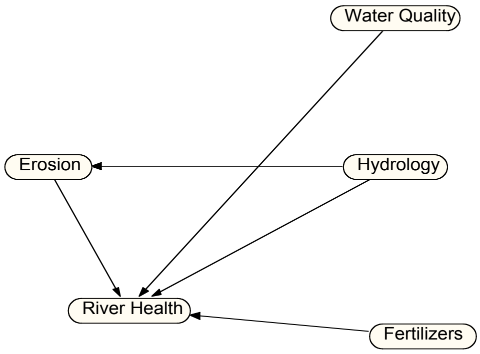

Figure 9. Graphical submodel for River Health.

Appendix B: Results of the grey-crowned babbler population abundance for two levels of reduced stock access

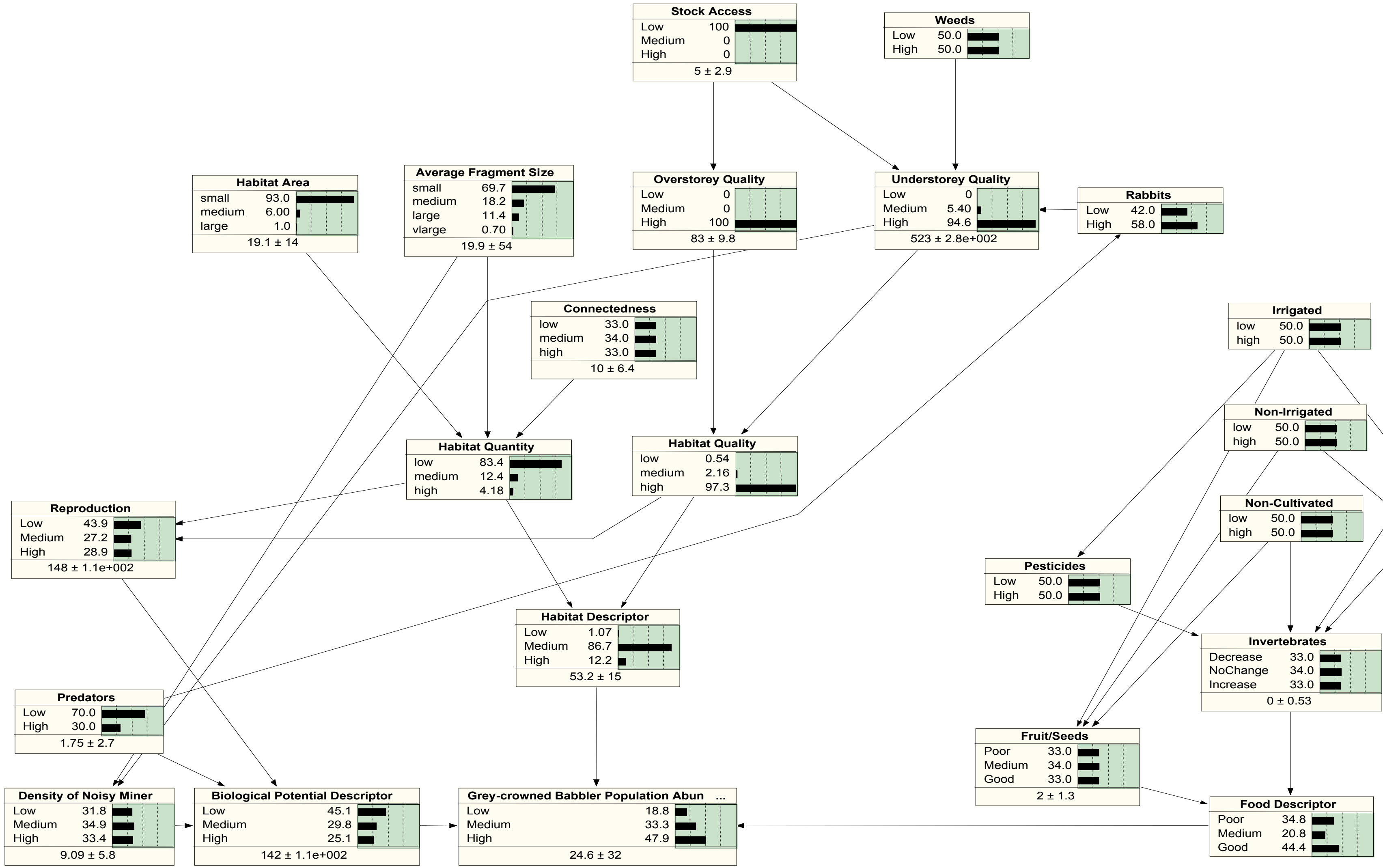

Figure B1: Stock Fencing Management Scenario - Low Access

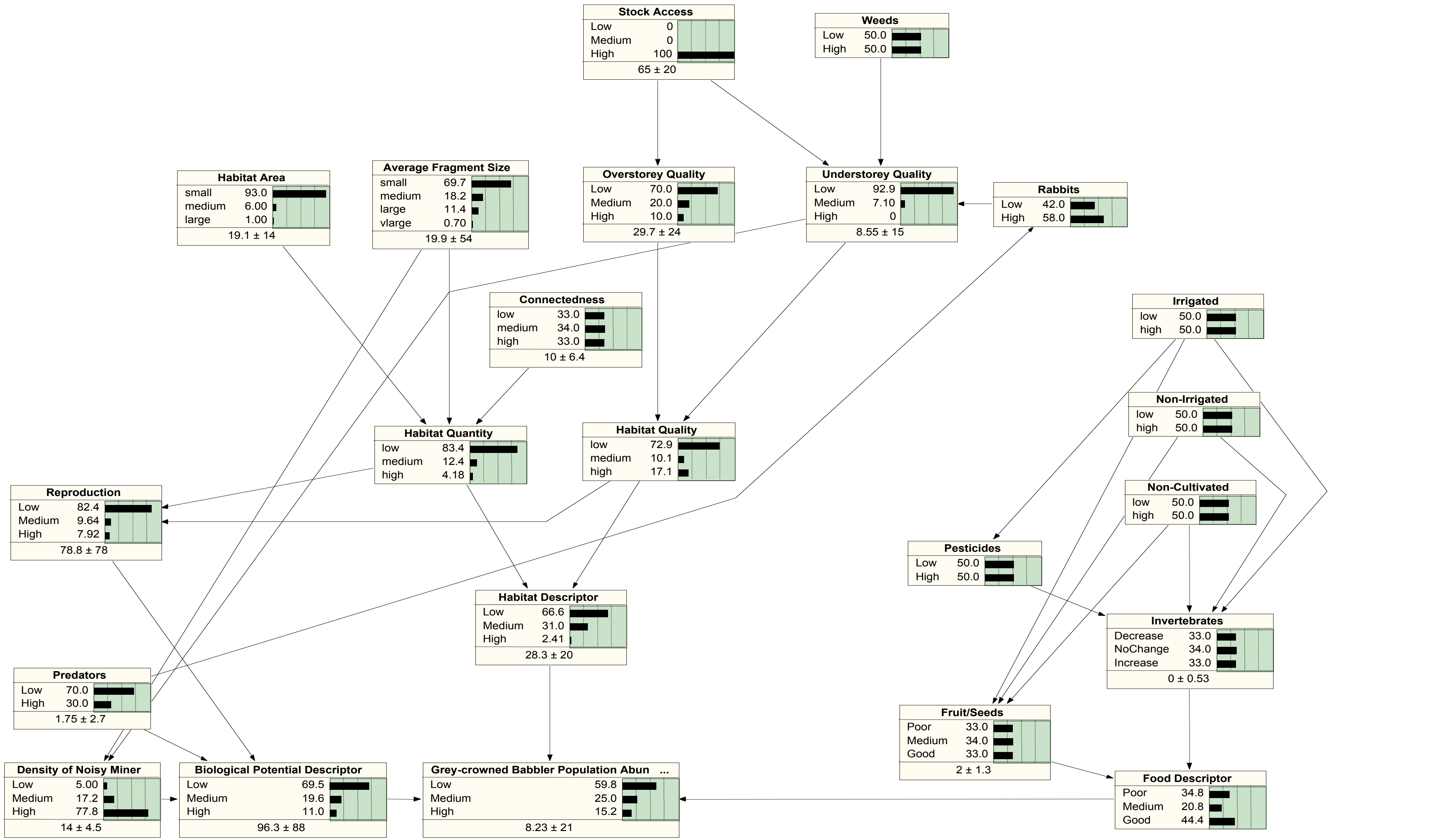

Figure B2: Stock Fencing Management Scenario – High Access