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Balancing tradeoffs between biodiversity and production in the re-design of rangeland landscapes

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Abstract
The conflict that exists between the competing needs of biological conservation and those of pastoral production is well recognised, however, few studies examine these conflicts due to their complexity and the uncertainty that surrounds these relationships. We describe a process for the development of a Bayesian Network model that examines the trade-offs between the conservation value of the landscape for a range of taxa (flora, mammals, birds, herpetofauna) and the primary production value under alternative land-use. We identify regional vegetation context and structural complexity as key landscape drivers of biodiversity. Simple scenarios were used to examine the influence of alternative land use activities on multiple components of biodiversity and demonstrate how preferred landscape designs can be determined. The application of this model as a planning tool for land management agencies or regional NRM bodies to develop policy or direct future investment at multiple scales is identified.

Introduction
The conflict that exists between the competing needs of biological conservation and those of agricultural production has been recognised globally. These conflicts can be expected to escalate as demands for global food production result in further expansion of agricultural areas (Cowie *et al*. 2011). Climate change impacts will likely pose additional risks to agricultural production and biodiversity (Phalan *et al.* 2011). Understanding the relationships and trade-offs between the production and biodiversity values of Australian rangelands is essential for sustainable rangeland use and the formulation of policy for on-ground investment activities.

Bodies responsible for natural resource management in the Australian rangelands provide financial incentives for management activities that result in expected conservation outcomes, but there are no planning tools to assess the economic implications of changed management. Some studies have re-configured land use based on economics and habitat suitability for a single species (e.g. Holzkamper and Seppelt 2007), none have examined multiple species because of the considerable uncertainty that surrounds these relationships. Bayesian Networks (BNs) provide statistical frameworks to allow examination of multiple interactions within complex systems and are beginning to be applied in environmental modelling (Aguilera *et al.* 2011). The objectives of this study were to (a) use expert opinion to assemble information about expected relationships between species richness and agricultural production activities in rangelands; and (b) describe the process for the development of a model to trade-off rangeland management with multiple components of biodiversity.

Model development

Model development followed the recommendations of Marcot *et al* (2006).

Step 1: Definition of model domain
A conceptual case study was developed for a semi-arid rangeland pastoral enterprise in western NSW (MAR 350-450mm), where short-term cropping, and establishment of exotic pastures (e.g. buffel grass) or saltbush plantations were considered possible.

Step 2: Development of influence diagram
An initial BN was developed based on an influence diagram that depicts causal links between variables. While the final model consisted of 34 nodes, a simplified form is shown in Fig.1. The central role of vegetation structural complexity was recognised (Catling *et al.* 2001) and captured by the varying degrees of ground, shrub and tree cover found in six land cover categories; pasture (sown pastures), woodland (native), riparian, invasive native scrub (INS), saltbush plantations and native grasslands. Landcover type influenced other habitat components such as logs and rocks, weeds and tree hollows, which strongly influence biodiversity (Gibbons *et al.* 2008). A habitat biodiversity value was calculated for major taxa by combining the influence of structural complexity and ecosystem productivity. Regional native vegetation coverage (regional vegetation) was identified as a major driver for prediction of diversity values of a patch (Burgman *et al.* 2005). An aggregate biodiversity value was then calculated.

It was assumed gross margins for agricultural production were primarily influenced by carrying capacity, soil type and position in landscape. The lowest carrying capacities occurred with highest shrub densities and lowest ground cover (Daly and Hodgkinson 1996).

Step 3: Review of the influence diagram
Experts reviewed and revised the influence diagram based on a combination of personal research experience and/or other published literature.

Step 4: Parameterisation
Values within the BN are quantified through conditional probability tables for each node. Conditional probabilities for each node are then specified for all combinations of states of their parent nodes, or for the single distribution in the case of childless nodes.

Childless nodes were populated with data from the region, or using scenarios (see below). All other nodes were populated using expert opinion drawn from within a group comprising; one expert for each of birds, mammals, reptiles and frogs; two experts for flora and three experts for primary production. Experts were asked to provide probabilities for the lowest and highest values and the program populated the remaining probabilities considering a linear trend between the corner points. These probabilities were then revised using the relevant experts by running combinations of land cover types with grazing histories to determine if the model performed as expected.

Step 5: Simple scenario development

Two simple scenarios were tested: conversion of native woodland and grasslands to INS in 10% increments (Fig. 2). Here, the model revealed that under both scenarios, primary production declines consistent with Daly and Hodgkinson (1996). In contrast, biodiversity declined as native woodland was converted to INS, but there was little negative impact on biodiversity when exotic pastures were converted to INS. While these figures represent biodiversity values as an aggregate of different fauna groups and vascular plants, the response by the individual groups is also available using our approach. This is necessary as differential responses are expected among the groups (e.g. Law *et al.* 2011).

Conclusion

We were able to describe a model that provides the current understanding of the relationship between biodiversity and agricultural practice based on expert opinion. Simple scenarios revealed that model performance aligned with generalised expectations from the literature. This type of BN modelling approach allows information (either qualitative or quantitative) to be synthesised and updated as new published data becomes available and may be suited to an adaptive management approach to land management (Ticehurst *et al* 2011). In order to validate these outcomes developing case studies and capturing broader expert opinion is required (Steps 6 & 7, Fig.1).

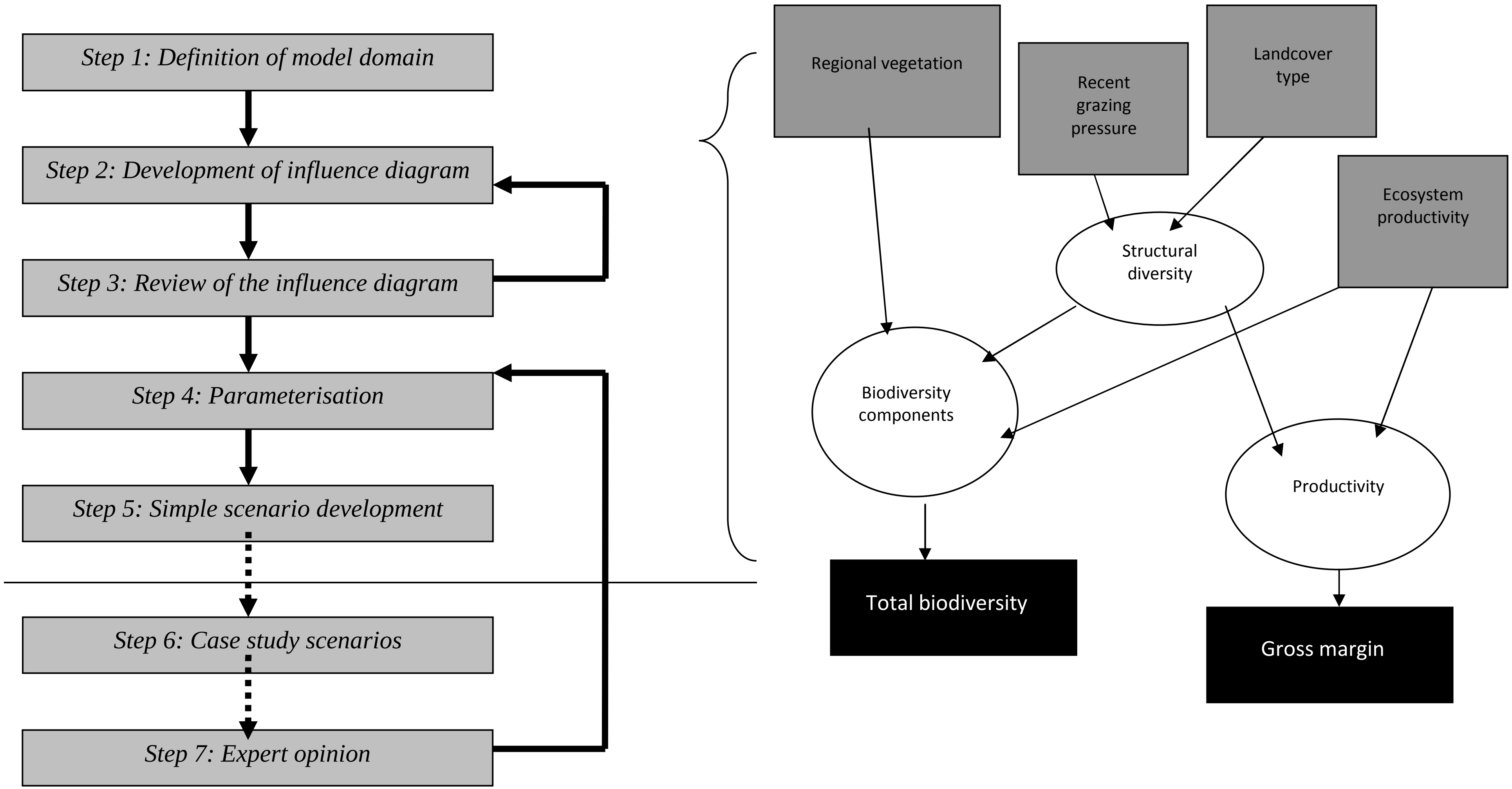

Fig. 1. Overview of the steps used to develop the BN model (left) with further steps required to validate BN model indicated by broken arrows. The influence diagram (right) shows outcomes (black boxes), of total biodiversity (species richness of plants and vertebrate animals) and gross margins predicted based on landcover type. Major environmental factors of influence (e.g. regional vegetation composition and extent) are indicated by shaded boxes.

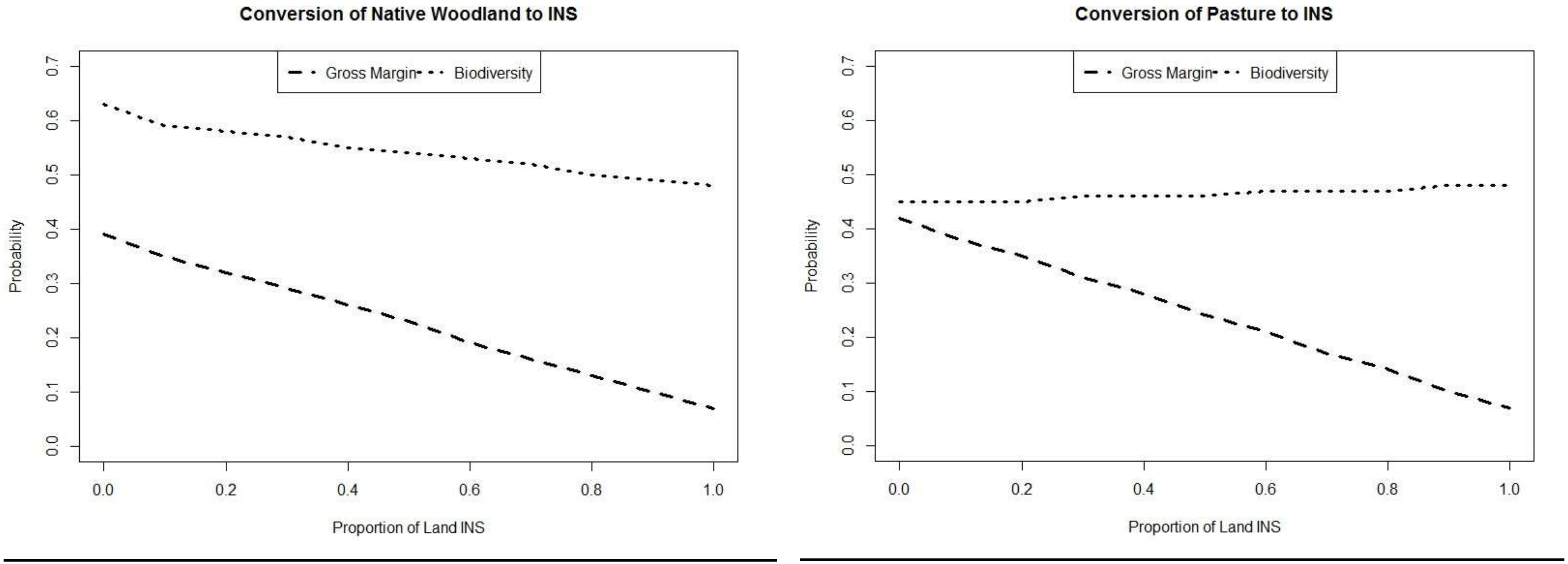

Fig. 2. Production and biodiversity outcomes for the conversion on native woodland and exotic pasture to invasive native scrub (INS). The y-axis represents the joint probability of medium or high biodiversity or gross margin.

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