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A decision-support system for the conservation management of the Gouldian finch.

Adam Liedloff[1], Damian Milne[2], John Woinarski[2]

1. CSIRO Sustainable Ecosystems, PMB 44, Winnellie, NT 0822.
2. NT Department of Natural Resources, Environment, The Arts and Sport,
   PO Box 496, Palmerston, NT 0831.

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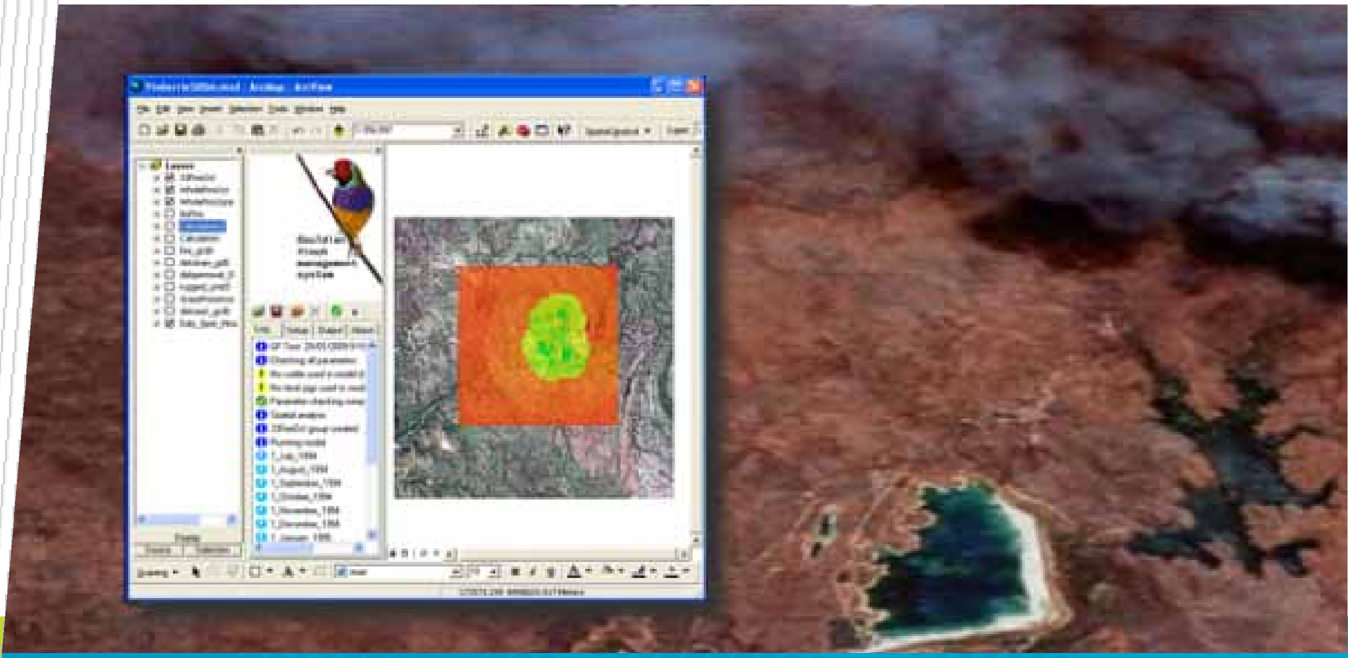

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Enquiries should be addressed to:
Dr Adam Liedloff
CSIRO Sustainable Ecosystems, PMB 44, Winnellie, NT, 0828.
adam.liedloff@csiro.au

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SUMMARY

In this project we apply a new approach to develop a computer-based, decision support model of Gouldian finch habitat suitability. The technique incorporates the best features of Bayesian Belief Networks, Geographic Information Systems and process-based simulation methods. The resulting model allows us to extrapolate from a point source, mechanistic, expert assessment of the likelihood of suitable Gouldian finch habitat to larger spatial and temporal scales.

We developed the model through the combination of a literature review and consultation with experts in the field. The model is applied to Gouldian finches at Yinberrie Hills (Northern Territory), which is the largest known population. It shows that this population persists because of the favourable combined of water accessibility, nest availability and seeding dynamics of a number of grasses.

The model provides a synthesis of the current understanding of Gouldian finch ecology and shows how disturbances such as fire and grazing influence the abundance, timing and distribution of seed production that is critical to these finches. The model simulations highlight periods with low seed availability during the wet season known to cause stress, and the favourable rocky areas that maintain a seed-bank through the dry season, close to nesting and watering sites. The model’s ability to track interacting processes and spatiotemporal variation in the landscape allows the implications of disturbance and change to be determined, thus aiding land management decisions.

While the current version is parameterised for Yinberrie Hills, the methodology is fully transferable to other areas and other species that dependant spatially and temporally dynamic resources.

The model is described in this report and has been provided for use by Northern Territory government staff and stakeholders.

1 INTRODUCTION

The tropical savannas of northern Australia are characterised by expansive tracts of native vegetation with low levels of intensive development. Nevertheless, recent evidence suggests that many species of native plants and animals in this region have declined substantially, and this decline may be accelerating (e.g. Woinarski *et al.* 2007 a,b). Some groups, notably granivorous birds and mammals, have shown a particularly marked tendency for decline, and many of these species are now recognised as threatened (Franklin 1999; Woinarski *et al*. 2001; Franklin *et al*. 2005).

The Gouldian finch (*Erythura gouldiae*) has shown considerable population reduction and range contraction. Now recognised as endangered, the Gouldian finch was historically common throughout much of the tropical savannas, but its distribution is now patchy and it has disappeared from much of its former range (Franklin 1999). Several factors have been suggested for this decline including altered fire regimes, grazing disturbance, commercial trapping for aviculture and parasite infections (Tidemann *et al*. 1992; Tidemann 1996). No single reason adequately explains the decline, but instead, it is likely that its endangerment arises from a complex interaction between landscape change and its specific habitat requirements.

While the Gouldian finch is possibly the most extensively researched of the threatened species in northern Australia (e.g. Tidemann 1990, 1993a,b, 1996; Tidemann *et al*. 1992a,b, 1999; Woinarski and Tidemann 1992; Garnett and Crowley 1994; Bell 1996; Franklin *et al*. 1999; Dostine *et al*. 2001; Dostine and Franklin 2002; Lewis 2007), like many savanna plant and animal species, there is limited data available about aspects of its ecology, life history and population processes.

The key to the ecology, and hence management, of the Gouldian finch is that its habitat is heterogeneous both spatially and temporally (Woinarski *et al*. 2005). The seeds that it requires for food are differentially distributed across the landscape, and their occurrence or abundance at any location will ebb and flow depending upon the grass species composition and season, with further variation superimposed by the incidence of fire, grazing and other factors (Garnett and Crowley 1994, 1995; Crowley and Garnett 1999, 2001; Dostine *et al*. 2001). Periods with low seed availability are critical as Gouldian finches appear less able to supplement their diet with insect protein compared with other finch species (Dostine and Franklin, 2002). Some grass species may be especially pivotal, providing seeds at a time when no other food resources are available (Crowley 2008). Habitat suitability is further dictated by the location and abundance of the tree hollows used for nesting and upon access to the freshwater. Granivorous birds require water on a daily basis, and, in this strongly seasonal environment, this resource may be distributed unevenly through time and be variably limiting across different seasons.

Different patches of the landscape will be suitable for Gouldian finches at some times and unsuitable at others; and the persistence of the Gouldian finch in an area will depend upon a complex package of resource dynamics hinged on a requirement that there will always be some sites in this fluctuating environment that offer enough of the right resources. This presents a complex management challenge, requiring an understanding of resource dynamics across spatial and temporal scales.

In this project, we seek to describe the environment of the Gouldian finch through modelling the spatial and temporal variation in resource availability and hence habitat suitability. Once this system is modelled, we can then use the model as a tool to consider how different management options (such as the imposition of a particular fire regime) may affect resource availability, at different times and in different areas. We can then use the predictions from the model to ensure that land management practices result in a proportion of the overall area retaining resources required by this species at all times.

Such landscape scale modelling and decision support tools have been developed and used for some analogous situations, such as for consideration of grazing options in savanna landscapes (Liedloff *et al*. 2001) and for vegetation dynamics in response to a range of fire regimes (Liedloff and Cook 2007). However, there are few precedents for the spatial and temporal complexity of the Gouldian finch situation, and the challenge is harder due to limitations in the knowledge of the ecology of this system.

2 MODEL DEVELOPMENT

The habitat suitability model developed for this project needed to consider the spatial context (i.e. distance to water, nests and food), the temporal context (i.e. bird breeding, plant phenology and water dynamics), dynamic feedbacks occurring in the system as well as system variability. Three modelling approaches were considered to undertake this task: process-based simulation models, Geographic Information Systems (GIS) and Bayesian Belief Networks.

Process-based simulation models are a bottom-up approach where the system being studied is broken down into measurable components with known relationships. By building a computer model with these known relationships with a set order of calculation, the model can then reproduce the system or subject in question. These models work well for physical systems where rules are known and precise calculations are possible. This approach does require considerable understanding of the system and rigorously measured relationships. They often require large amounts of development time and expertise, and so when developed, provide a good predictive or diagnostic scientific tool. A number of process based grass models in the tropical savannas were considered for this project, but none were found to be suitable.

Process-based simulation models by their nature lump the processes into rules and time-steps and rarely allow for inclusion of natural variability. The variability present in the tropical savannas and of importance to Gouldian finches is extremely difficult to model without a very detailed understanding of the processes and plant distributions.

Geographic information systems (GIS) are designed to manage spatial data, but offer limited ability to model especially with a temporal component.

Bayesian based models using probabilities may better encapsulate variability in the system, but require detailed understanding or field data to initialise such probability tables. Alternatively, Bayesian models can be propagated with expert knowledge in the absence of detailed quantitative data. However, these models do not allow dynamic feedbacks or handle temporal aspects.

Given the individual strengths and shortcomings of each of these approaches, we recognised that all three approaches were required to solve this problem. These will be discussed in the following sections; (2.1) the development of the Bayesian Belief Networks (to predict habitat suitability and the probability of grass species providing seed at a given position and time), and (2.2) the development of an integrated model to link the Belief Networks, GIS and process-based component with a user interface.

While the model was developed using data for a single site (Yinberrie Hills, NT), the assumptions and approach used can readily be transported to any other site and the system would be applicable, with minor modifications, to other areas where the Gouldian finch occurs.

2.1 Bayesian Belief Networks

Bayesian Belief Networks (also known as belief networks, causal nets, causal probabilistic networks, probabilistic cause effect models, and graphical probability networks) present a network of relationships using Bayes Rule, named after Reverend Thomas Bayes (1702-1761) who described this basic law of probability. He found that for any two events (A and B) the probability of B given A has occurred equals the probability of A given B has occurred, times the probability of B divided by the probability of A. This law turns out to be very powerful and allows all the probabilities in a network to be updated when any one piece of information changes. This rule also allows a belief network to calculate not only the probability distribution of consequences given the cause, but also determine the probability distributions of the causes given the consequences (Uusitalo, 2007)

It wasn’t until the 1990’s that the Bayesian Networks were developed using Bayes Rule using computer software. These were initially used for financial risk assessment and medical diagnosis. Since that time a large number of scientific fields have identified the value of this approach including ecology and natural resource management. Bayesian belief networks (BBNs) are graphical models consisting of nodes (boxes) and links (arrows) that represent system variables and their cause-and-effect relationships (Jensen, 2001). BBNs consist of qualitative and associated quantitative parts. The qualitative part is a directed acyclic graph (cause-and-effect diagram made up of nodes and links) while the quantitative part is a set of conditional probabilities that quantify the dependencies between variables represented in the directed acyclic graph). Networks developed strictly for modelling reality are referred to as “belief nets”, while those that include a mix of value and decision making are referred to as “decision nets”.

Some debate exists over the ability of these models to work if the probabilities upon which they are based are not exact. In fact, these models are found to be robust when using approximate probabilities and even a subjective “best guesses” provides good results (Norsys, 2007). The ability to use imperfect knowledge to make strong conclusions using BBN is one of the biggest benefits of this approach and the reason it was used in this project.

BBNs are becoming an increasingly popular modelling tool, particularly in ecology and environmental management (Marcot 2006; Nyberg *et al*. 2006). This is because they are diagrammatic models that have predictive capability and they allow uncertainty to be accommodated in model predictions by using probabilities. In ecology and natural resource management they have been used to integrate qualitative and quantitative knowledge about system dynamics (see Bashari et al., 2009, Smith et al., 2007b, Pollino et al., 2007 and McNay et al., 2006 for example), engage stakeholders in decision making (Cain 2001, Cain et al., 2003, Smith et al., 2005, Smith et al., 2007a) and support adaptive management (Henriksen and Barleba, 2007, Nyberg et al., 2006 Smith et al., 2007a).

Each variable used in the models can either represent a quantitative state such as water level, or a qualitative assessment such as habitat suitability. Each has a small number of states described (e.g. water level may be high, low and dry), but one limitation of Bayesian networks is the inability to handle continuous data. Once the network has been parameterised the probability of any variable can be determined by the current state of all other variables in the network, providing an effect decision support tool. The certainty probabilities used can range from precise values obtained from collected data in a large population (cases) to a best guess estimate by an expert (or belief) of the likely chance for each category of a variable given the other influences.

Bayesian Belief Networks were used as the underlying modelling methodology in this project. This approach was chosen as conventional process-based models of savanna function were not available or suitable, there were limited data available and the expert-based understanding of Gouldian finch population and tropical grass dynamics is conducive to developing belief networks in the time available for this project. Using this methodology, the aim of the model was to estimate the probability of a given pixel (a point in space) being suitable for finches at a given time. To include seasonality, and cope with spatial variability, the use of belief networks needed to be integrated with a GIS and a process-based component to provide the additional data.

The model is not intended to predict population size, population dynamics, the current location of birds or actual patterns of seed resources and consumption across the study area. Rather, the approach used considers likelihoods. For example, a habitat suitability layer with high suitability over the whole area would suggest conditions are good for the birds and they would likely be found in any location (or potentially outside the map). In contrast, one small area of suitable habitat in a map suggests an increased likelihood that the population would be found in, and dependent upon, that area. A map consisting primarily of poor habitat does not mean an absence of birds, but rather that conditions are harsh and the population, if present, would likely be under some stress. This approach also allows aspects not often considered in habitat assessment to be included in the simulation. For example, seasonal requirements such as water, nesting sites and fluctuating food resources result in a dynamic realisation of the spatial suitability for the Gouldian finch. This model attempts to cover these aspects in the predictions.

Two BBNs were developed to determine habitat suitability for Gouldian finches at a given point in space at a given time. The BBN has been divided into two networks to allow the *Seed Availability BBN* to be optimised for a range of grass species before providing probabilities to the *Habitat Suitability BBN.* An individual BBN is required for each key grass species present in the analysis to determine habitat suitability.

While Bayesian Belief Networks do not easily allow for temporal modelling with time-steps and dynamic feedback loops, we can use these “expert systems” to provide the likely state of the system at a given time. This modelling project has been designed to incorporate this knowledge system within a GIS framework that will provide the input values each time-step, store relevant factors in spatial layers and control the process of managing time (i.e. track rainfall, season etc).

These BBNs are probabilistic and the range of probabilities provided allows for uncertainty and natural variation to be added to this model. Once the overall BBN structure is considered suitable, all conditional probability tables will need to be filled using either field based data or expert opinion.

2.1.1 Elicitation of knowledge

The understanding behind this model was obtained from an extensive literature review, an expert workshop with bird ecologists, grass ecologists, population ecologists, and additional meetings with researchers to ensure a regional scope was obtained and the model was not specific to the site of development. The attendees at the expert workshop in Darwin (5th June 2007) were Adam Liedloff (CSIRO Sustainable Ecosystems, Darwin), John Woinarski, Gay Cowley, Peter Dostine, Jenni Low Choy, Alaric Fisher, Don Franklin (Northern Territory Department of Natural Resources, Environment and the Arts) and Stephen Garnett (Charles Darwin University). Additional discussions were held with Sarah Legge (Australian Wildlife Conservancy, Mornington Station, WA).

2.1.2 Habitat suitability BBN

The primary habitat suitability BBN is used to determine the habitat suitability based on the three factors considered critical to the survival of the Gouldian finch: food, water and nest sites (Figure 1). This network considers the distance to resources (nests and water) and the current seed availability of any pixel to provide a probability of suitable habitat. This finch suitability probability will be determined for each pixel in a spatial map and the total site suitability will involve assessing the proportion of all suitable pixels. This measure is effectively an index from poor to good.

This section provides a description of the nodes used and the processes captured. It is important to remember that each BBN is for a given pixel at a given time. While it is important to understand the seed availability and general habitat suitability of each pixel in the study area, the overall site suitability will also be required. This means some areas may provide finches suitable habitat (pixels near nests, pixels with *Triodia* sp) while other pixels are not suitable (i.e. no grass seed available after first rains). This also means we can determine the impact of various fire management options.

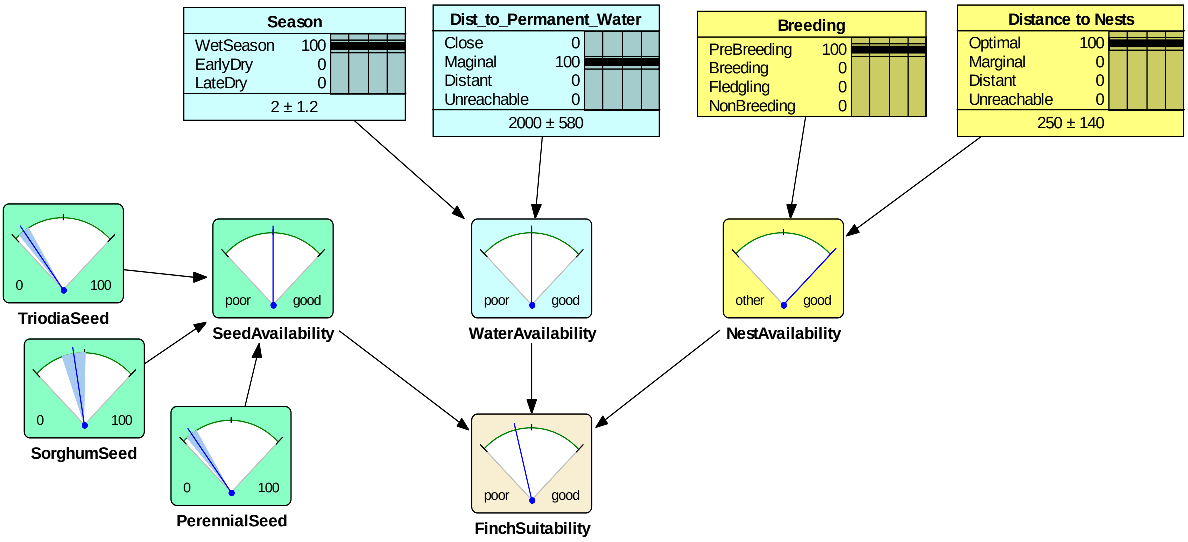


Figure 1. Gouldian finch habitat suitability Bayesian Belief Network with nodes relating to water (blue), nesting (yellow) and seeds (green).

Water Availability

The *water availability* node is designed to provide an indication of the proximity to permanent water of the pixel in question. This represents finch available water, so the water must be suitable for finches to drink and is influenced by Gouldian finch flying distances. The *distance to permanent water* node is based on a measure of the distance to nearest water in metres. Currently the cut-offs are classified as close (0-1000m), marginal (1000-3000m), distant (3000-7000m) and unreachable (very distant or not available, >7000m) (Sarah Legge, *pers. comm.*). If other factors are considered important in influencing this water availability (i.e. feral pig presence in the lowlands diminishes water quality and availability) these additional processes can be added in future.

Nest Availability

Both nest availability in the form of hollows and the proximity of nests to water and food supplies are important for the Gouldian finch. During breeding (nest preparation to fledging) nest availability dictates habitat suitability based on the daily requirements to obtain food and water while also defending the nest or returning to feed nestlings. Currently the distance to nests (metres) is classified as optimal (0-500m), marginal (500-2500m), distant (2500-7000m) and Unreachable (>7000m).

Seed Availability

The expert workshop agreed that seed availability was the critical aspect to understand in order to determine the suitability of an area for the Gouldian finch. It was also agreed that different grass species provided seeds at different times based on their life-history strategies and phenology. For this reason one BBN encompassing all grasses was not feasible, and did not represent the pivotal ecological and management requirement for the mixed occurrence of grass species with different phenologies. While an individual seed availability BBN is used for each main grass species, different category cut-offs and probabilities are required to differentiate the different plant responses to seasonal change and disturbance (see Appendix B). In the Yinberrie Hills (NT, see section 2.2) area of this study, the grass species providing main resources for the Gouldian finch are considered to be the perennial grasses *Triodia bitextura*, *Chrysopogon fallax* (including *C. latifolius*) and *Alloteropsis semialata* and the annual *Sorghum (Sarga) intrans* (Dostine *et al*. 2001; Dostine and Franklin 2002; Woinarski *et al*. 2005; Lewis 2007). For a detailed description of the seed availability BBN see the next section.

Finch Suitability

The final probability of any pixel being suitable for Gouldian finches is a combination of the nest availability (during the breeding season only), water availability and seed availability. The relative importance of each of these properties on the final measure can be modified through the probabilities provided. These probabilities are provided in Appendix B.

2.1.3 Grass species BBN

The second BBN is used to determine the likelihood of seed being present as food during a given time-step (Figure 2). This BBN needs to be defined for each grass species considered important and present in the landscape. This expert system allows for the differences between annual sorghum, *Triodia* in Western Australia and other perennial grasses to be predicted each wet season.

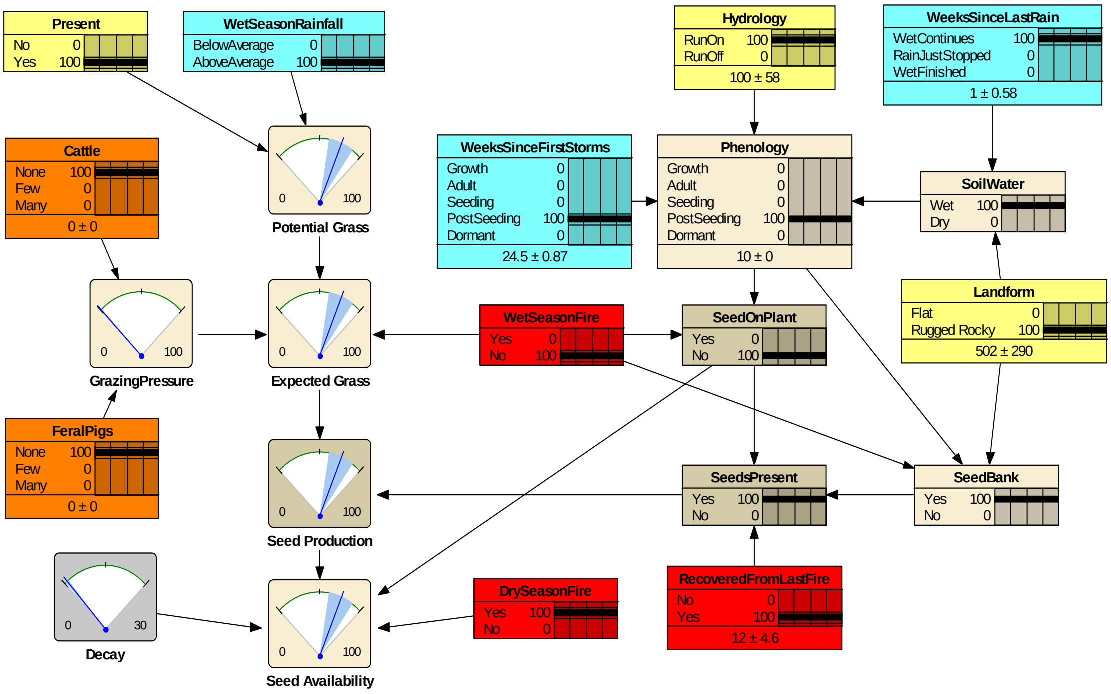


Figure 2. The general grass seed availability Bayesian Belief Network with nodes requiring input values displayed for GIS spatial information (yellow), rainfall related information (blue), fire (red), grazing (orange) and decomposition and loss of seeds (grey).

The nodes included in the BBN should provide the dynamics needed to cover the range of grass processes important to the Gouldian finch provided as a conceptual diagram provided in Figure 3 and based on the workshop discussions. This section provides a description of the nodes used and the processes captured to determine both the probability of parent grass biomass and the subsequent probability of available seed abundance.

Grass species presence (Present node)

The *Present* node indicates the chance of the species of interest being present in the pixel. This is currently determined from the species distribution models (see section 2.2.2), which provide a probability of the species being present in a pixel. The model allows the user to define presence in one of two ways; using the probability of presence from the models as the likelihood of being present or specify a cut-off value for each species that is used to determine if the species is present or absent.

Potential Grass

This node provides an indication of the potential grass abundance possible in the pixel based on the fact that the grass is present and on the current volume of wet season rainfall. The fact that we don't know the total wet season rainfall during the wet season isn't critical as grass won't seed until either flower initiation or seeding stage, by which time we will know the rainfall fallen to date and how it is likely to have influenced plant biomass.

Expected Grass

The expected grass abundance is determined by the relationship between *potential grass* abundance, the *grazing pressure* and *wet season fire*. Grazing pressure is determined by the presence of cattle and feral pigs in the pixel in question. The influence of grazing on each grass species is captured in the probabilities of grass reduction under the different grazing pressures. For example, a grass sensitive to grazing, trampling or pig digging or a species preferred by cattle may have a greater reduction in abundance than a species not affected by grazing.

Seed Stage

Before the probability of *seed availability* can be determined from the *Expected Grass* abundance we need to determine if the grass is seeding in the current time step. This is determined through two pathways after we ensure the grass has recovered from the last fire (i.e. *Triodia* sp may take 2-3 years after a fire before flowering). The current growth stage of the grass is estimated from the *number of weeks since the first storms* (or a measure of wet season water availability, time since germination and growth conditions). The different cut-off values for each grass species will capture the different timing of seeding. While a plant is in growth or dormant stage, no seeds are available (except for Sorghum, which has seed bank available on the soil surface during the dry season while the plant is dormant). Research has also shown decreasing soil water will force grasses to flower as a mechanism to ensure seed is set before the end of the wet season (Stephen Garnett, Sarah Legge *pers. comm.*). The BBN also includes a *Soil Water* node affecting seed stage. *Soil Water* is determined by a count of the *Weeks Since Last Rain* and the *soil* type. When the soil is deemed to be dry (or drying) grasses in the growth stage will flower and provide seed. Under most circumstances this will not have any effect as the growth stage of the grasses is relatively short during the early wet. It may however influence sorghum, which is growing for 4 months before flowering. It will then be important during short wet seasons due to delayed onset or early termination of rains.

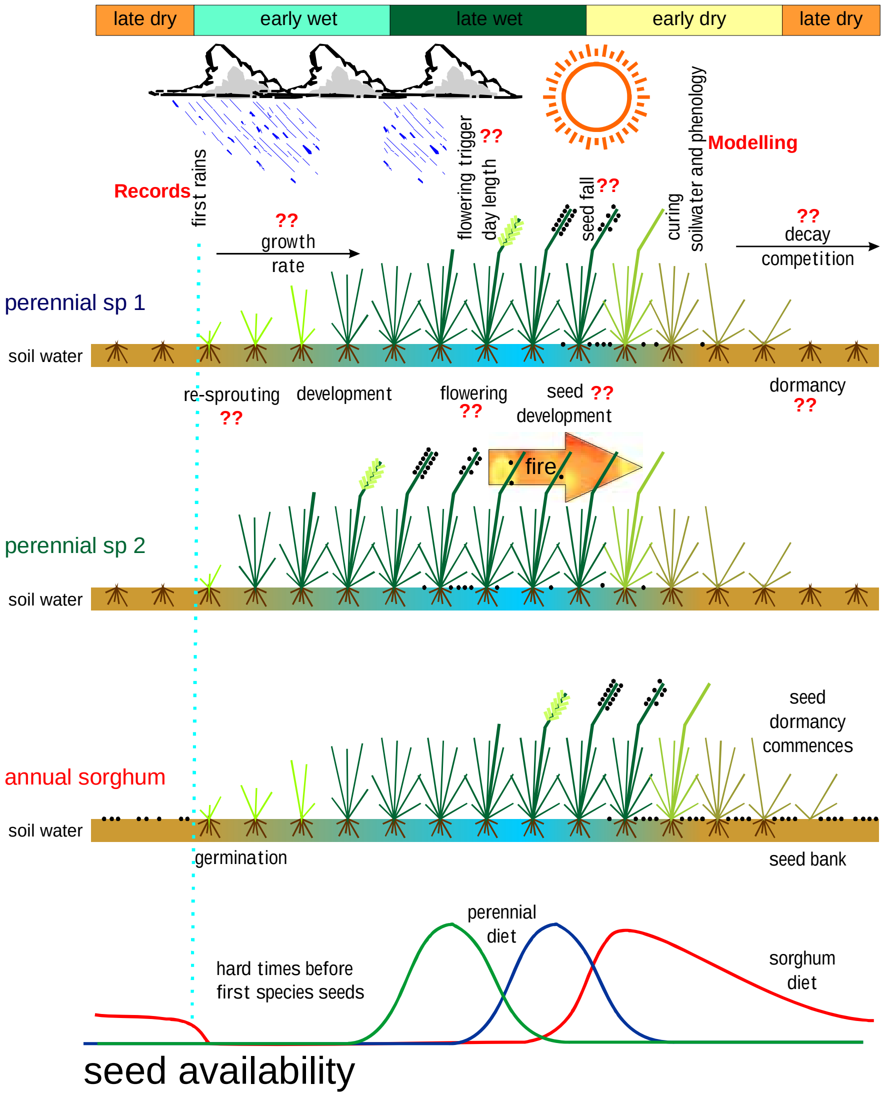


Figure 3. Theoretical representation of grass seeding dynamics and inputs required to model Gouldian finch seed availability. Question marks signify areas of uncertainty or where additional processes operate that are not currently defined in the model.

Seed Availability

The final probability of seed being available is determined from the *expected grass* abundance, whether the grass is in *seed stage* and whether there has been a *fire since last wet*. From workshop discussions it was suggested dry season fire does not remove the seed bank, but actually assists birds in finding seed through removing ground litter and senesced grass. A dry season fire therefore increases the accessibility of *Sorghum* seed during the dry season in locations with a rocky substrate.

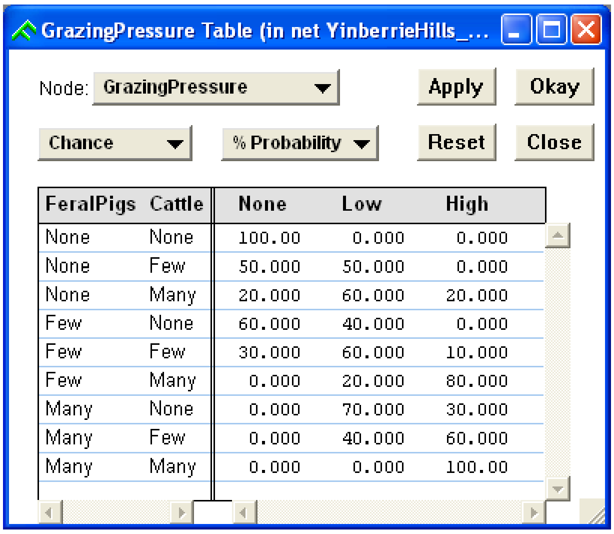
Fire

There is currently limited ability to modify the parent plant abundance or seed availability by burning after the first storms and germination. Wet season fires will reduce the seed abundance for the following year up to the next grass germination rains. An additional node of *Number of*

Fires Last Decade was considered to capture the effect of fire frequency on grass abundance, but is currently not included in the BBN. This could be useful if a grass species becomes more abundant or is more likely to occur with frequent or infrequent fires (i.e. sorghum may be more common in high fire regime while *Triodia* may disappear).

2.1.4 Filling the BBNs with probabilities

Probabilities can be supplied to the BBNs in one of two ways. If a series of observed outcomes or cases (i.e. No Cattle + Few Pigs = Low Grazing) are available each case can be entered into the Belief Network. The range of responses for each system state determines the resulting probabilities. The second approach is to provide the probabilities for each outcome based on each combination of parent node states. Figure 4 provides an example of the probability table to determine the state of the *GrazingPressure* node from the cattle and feral pig presence node states. This is where either field based data or expert opinion is used to provide the probabilities and the spread of probabilities gives a measure of the variability of the final outcome. For example, with no pigs and no cattle we are 100% confident we have no grazing pressure in the system. Of course this could have been set as another value (none .95, low .05 high 0), which would suggest that there is additional grazing pressure (5%) by a source not covered by feral pigs and cattle. Other rows in Figure 4 provide the relative importance of pigs over cattle or vice versa. For example, many cattle and few pigs in this example results in 80% chance of high grazing and 20% chance low grazing while many pigs and few cattle only resulted in 60% high and 40% low pressure. When the table is broken down into the critical states, it is generally a logical task to provide the outcome of each particular state. We may find that other nodes not currently included are also important in determining *GrazingPressure*. We would expect that feral pig disturbance would be greater in the wetter lowland areas, so we could add a conditional link between *hydrology* or *soil* and *grazing pressure*.



Node: GrazingPressure

Chance

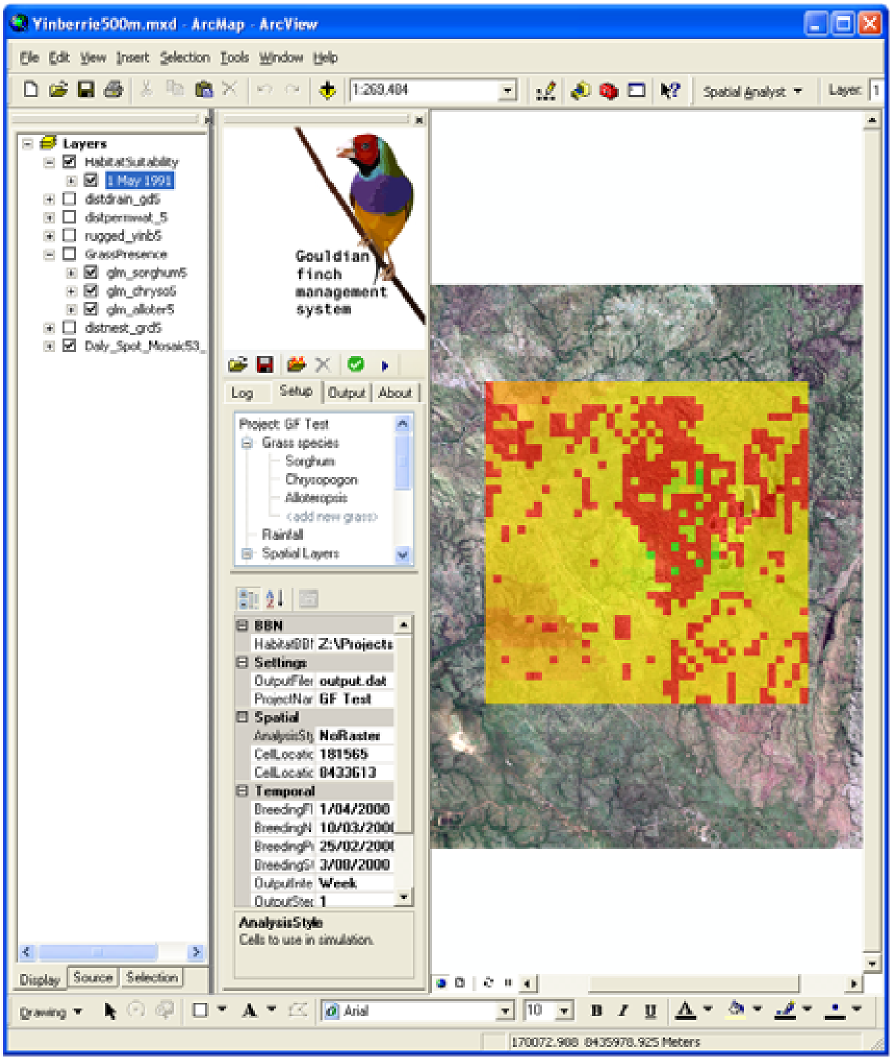
% Probability

FeralPigs	Cattle	None	Low	High
None	None	100.00	0.000	0.000
None	Few	50.000	50.000	0.000
None	Many	20.000	60.000	20.000
Few	None	60.000	40.000	0.000
Few	Few	30.000	60.000	10.000
Few	Many	0.000	20.000	80.000
Many	None	0.000	70.000	30.000
Many	Few	0.000	40.000	60.000
Many	Many	0.000	0.000	100.00

Figure 4. Example of a BBN probability table from Netica for the GrazingPressure node with parent nodes of Cattle and FeralPigs presence with the states none, few and many. Probabilities are presented as percentages.

2.2 Integrated model and user interface

An integrated modelling framework and user interface was developed to read daily rainfall records and track grass phenology (Figure 5). It also performs the task of reading data from GIS raster grid layers, filling the required findings into BBN nodes, linking the BBNs required for each pixel and returning a final habitat suitability value to the output GIS layers. The user interface and model integration was developed as a dockable window component for ARCMap (ARC Framework, ESRI) using the C# programming language (.Net 2005, Microsoft Corporation). This allows easy use of the model in a GIS environment familiar to many users and highlights the importance of spatial data in this project. The model therefore requires ARCGIS (ESRI) and Netica (Norsys) software installed on a Windows® based computer.



BBN
HabitatBBI Z:\Projects
Settings
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BreedingFl 1/04/2000
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BreedingP 25/02/2000
BreedingSt 3/08/2000
OutputInte Week
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AnalysisStyle
Cells to use in simulation.

Figure 5. The GIS application window showing the Gouldian Finch Management System user interface and spatial output in ARCMap (ESRI).

2.2.1 Spatial analysis

The spatial data used by the model is provided in a GIS environment (ARCMap, ESRI) and suitable surrogates for model variables were found from readily available data. For example whether a pixel was water shedding or water receiving affects the germination time, and therefore seeding time, of grasses. The distance to watercourses was used as a measure of this factor with pixels close to water courses assumed to be water receiving or run-on pixels.

The resolution of the analysis is defined by the data layers supplied by the user. As the underlying Bayesian belief network is spatially implicit (i.e. it will simply determine the probability of suitable habitat for finches for any location at a given time) the GIS data layers are required to provide the spatial data and define the simulation resolution. Regardless of spatial resolution used, there are other data limitations affecting the spatial analysis. One example is the ability to represent fine scale variability in processes such as rainfall, resulting from cloud bursts in the wet season. This patchy, fine-scale rainfall variability drives seed germination and the resulting timing of seeding that is critical in providing food resources to finches at a time when food is generally scarce. Such variability is not captured in regional weather station daily climate data. A full bottom-up analysis of the system would allow every pixel to receive rainfall at different times, potentially as a stochastic realisation of the rainfall data, but this approach is beyond the scope of this project. For this reason a number of assumptions such as uniform rainfall over the analysis area are currently included in this model.

In the present version of the model, each pixel is assessed independently and there is no interaction between pixels. This interaction would be required if dynamic grass species presence/absence layers were needed to model the colonisation of a pixel based on the presence of the species in surrounding pixels.

The pixel size, the extent of analysis area (number of pixels to analyse), time step and interval determine the computation time of a given simulation. There is a trade-off between spatial and temporal resolution and processing time. The model is not restricted to any specific pixel size and fine temporal and spatial scale runs can be performed, but it must be realised this will result in increased computation time. Initial simulations were performed with hectare grid pixels, but the time required to process this detail was excessive and so 500x500 metre pixels were used for simulations in this report. A grid area of 40 by 40 pixels (400 km^2) was used.

Both the development of the model and the results presented in this report are based on Yinberrie Hills, Northern Territory (132^{o}03’53”S, 14^{o}08’E, Figure 6), because this site is considered to support the largest known population of the Gouldian finch, and because much of the most intensive research has been conducted at this site. The spatial data used is discussed in the following sections.

Figure 6. Map showing the location of the Yinberrie Hills study area and the 400km^2 analysis area for this study.

2.2.2 Distribution of key grasses

Four key grass taxa were considered in this study - *Alloteropsis semialata, Chrysopogon fallax* (including *C. latifolius*), *Sorghum intrans* and *Triodia bitextura* as these are known to provide the majority of the seed resources to the Gouldian finch populations. These grass species were recorded in six transects ranging from 2.6 to 4.6 km in length, located to sample most of the environmental variation in the Yinberrie Hills (and adjacent lowland) area (Figure 6). Each transect was divided into an uninterrupted series of 50 m segments. Species were identified as either present or absent at each metre along the transect, within a 50 cm x 25 cm quadrat. An abundance score for each grass species was then calculated for each 50 m segment from the count of all quadrats where the species was detected as ‘present’.

Abundance scores were converted into ARCINFO GRID format with a pixel resolution of 100 m x 100 metres using known geographic coordinates at the mid-point of each 50 m segment. Where two mid-points occurred in a given pixel, the mean of the abundance scores was attributed to the grid pixel.

We then used these data to develop distributional models for each of the key grass species across the study area. Seven environmental variables were used as predictors of grass distributions:

- **elevation** (m), derived from a digital elevation model;
- **slope** (%),derived from a digital elevation model;
- **topographic ruggedness** (an index calculated from the range in cell values within a 3 x 3 cell neighbourhood), derived from a digital elevation model;
- **annual mean temperature** (°C), derived from BIOCLIM;
- **annual rainfall (mm),** derived from BIOCLIM;
- **distance (m) to permanent water** (rivers and permanent water holes); and
- **Normalised Difference Vegetation Index** (NDVI), a measure of vegetation ‘greenness’ derived from satellite imagery.

Each environmental variable was incorporated into the GIS and values for all seven variables were derived for each corresponding grass species grid cell.

Generalised Linear Modelling (GLM) was used to model grass species occurrence across the Yinberrie Hills study area. A Poisson error distribution and log function with a backward stepwise process was used to derive minimum adequate models (Table 1). The percent of the deviance captured was used to assess the accuracy of the models. Finally, GIS was again used to derive ‘probability of occurrence’ maps (Figure 7) for each species using the logit transformation (Equation 1).

$$probability = \frac{e^{model}}{(1 + e^{model})} \qquad \text{Equation 1}$$

To achieve better representation, *Triodia bitextura* was modelled in two separate areas within the study area (divided into two soil type: units Wd13 and LK23, Digital Atlas of Australian Soils, 1991) and the resulting maps appended together.

Subsequent to their derivation, the distributional models were field-tested to assess their accuracy. Forty-seven sites were sampled (Figure 8). Sites were selected to cover a range of probabilities for each of the target grass species and located at the centre of a 500 m X 500 m grid cell; the resolution used for the final Gouldian finch habitat suitability modelling. Sites were then surveyed for the four species using a 150 m X 10 m transect.

The results of this field-testing are presented in Table 2, and these reveal some interpretational issues. The model for *Sorghum intrans* predicted almost universally high likelihood of occurrence, and hence could offer little discrimination in comparing observed with expected. The observed occurrence for the three other species was high (i.e. all species were recorded from most sites), even at sites where the models predicted low likelihood of occurrence. This unexpected high incidence is probably due to the relatively large size of the testing sample sites (150 m x 10m), relative to the small sampling units (50 cm x 25 cm quadrat) on which the initial model was based. Predictions from the model were best for *Chrysopogon* (observed in only 2 of 13 sites where likelihood of occurrence was <50%, but observed in all 34 sites where expected occurrence was >50%) and worst for *Triodia* (observed in 16 of 19 sites where likelihood of occurrence was <50%, but only in 21 of the 28 sites where expected occurrence was >50%).

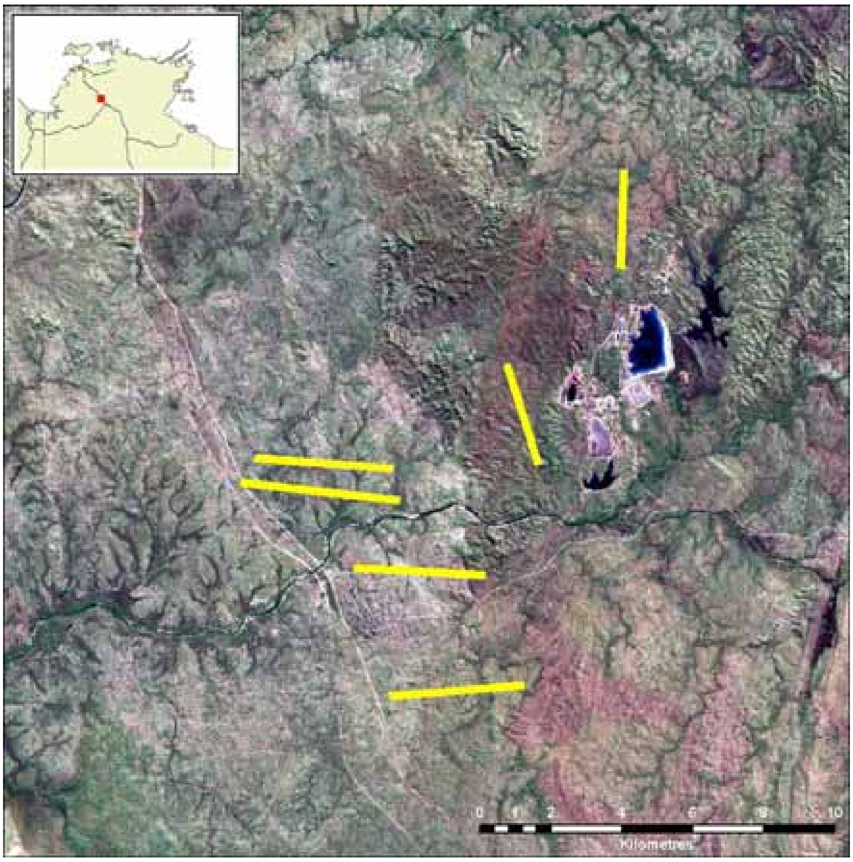


Figure 7. SPOT image of study area showing locations of transects used for the description of the distribution of grass species.

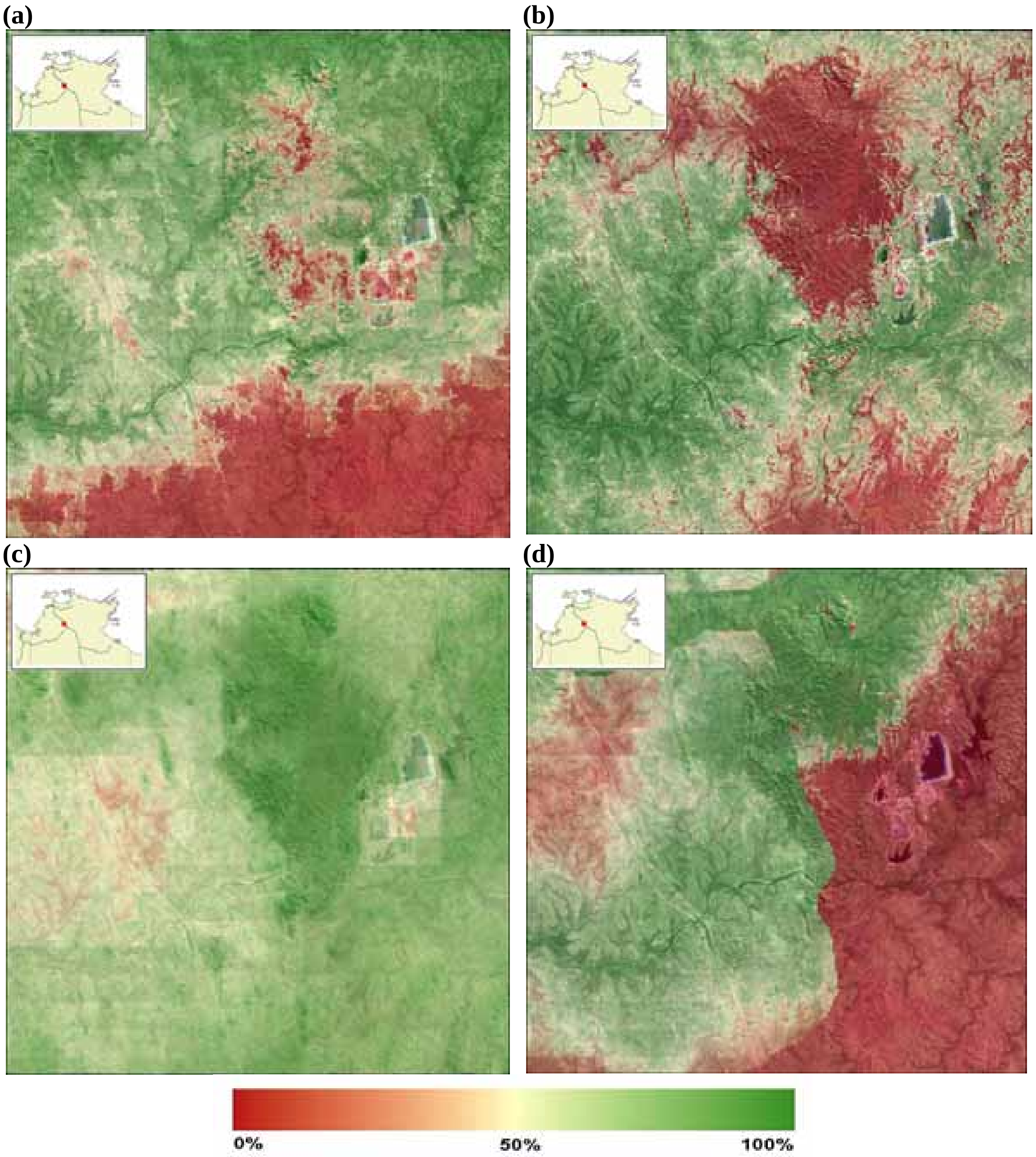


Figure 8. Probability of occurrence maps of the Yinberrie Hills derived from GLM modelling for (A) *Alloteropsis semialata*, (B) *Chrysopogon fallax*, (C) *Sorghum intrans* and (D) *Triodia bitextura*. Green shades depict high probability whereas red shades depict low probability.

Table 1. Summary of results from Generalized Linear Modelling of Yinberrie grass species showing parameter estimates and explanatory power (percent of deviance explained) of the minimum adequate model. Probability levels **P<0.05, ***P<0.005.

Species	Estimate	SE	*P*-value
Alloteropsis semialata (deviance captured = 29.3%)			
Constant	-193.373	31.061	
Elevation	-0.016	0.007	**
NDVI	0.017	0.004	***
Ruggedness	0.080	0.017	***
Temperature	4.705	1.148	***
Rainfall	0.064	0.004	***
Chrysopogon fallax (deviance captured = 33.7%)			
Constant	-12.951	3.599	
Elevation	-0.050	0.002	***
Rainfall	0.020	0.004	***
Slope	0.516	0.069	***
Ruggedness	-0.202	0.037	***
Sorghum intrans (deviance captured = 32.1%)			
Constant	-25.394	14.533	
Elevation	0.025	0.003	***
Slope	-0.057	0.020	***
Ruggedness	0.074	0.012	***
Temperature	1.389	0.539	**
Rainfall	-0.015	0.002	***
NDVI	0.013	0.002	***
Triodia bitextura (soil type Wd13) (deviance captured = 27.7%)			
Constant	-114.913	23.360	
Elevation	0.059	0.006	***
Slope	-0.164	0.034	***
NDVI	-0.043	0.003	***
Temperature	4.654	0.860	***
Distance to water	-0.001	0.000	***
Triodia bitextura (soil type LK23) (deviance captured = 68.0%)			
Constant	-862.462	170.109	
Elevation	-0.077	0.034	**
Slope	-1.058	0.184	***
Distance to water	-0.002	0.001	**
NDVI	0.080	0.038	**
Rainfall	0.806	0.160	***

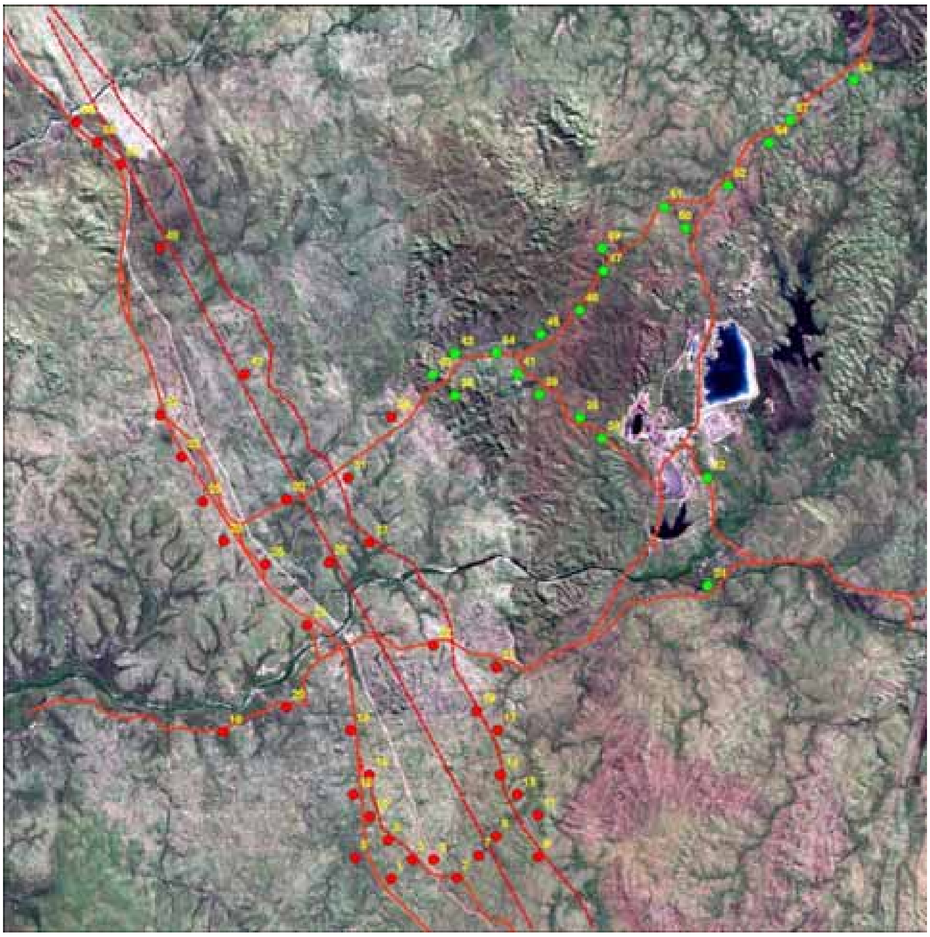


Figure 9. Pre-selected location of sites used to verify distributional models for grass species. Note that only 47 of these 58 sites could be visited, due to logistic constraints.

Table 2. Summary of field-testing for verification of grass distributional models. Values in the body of the table refer to the number of sites at which the species was recorded / the number of sites sampled for that likelihood class – e.g. 4/7 for *Triodia bitextura* 0-10% likelihood means that 7 sites were sampled in which the predicted likelihood of occurrence for *Triodia bitextura* was between 0 and 10%, and of these 7 sites, *Triodia bitextura* was recorded in 4 of them.

Predicted likelihood of occurrence (% range)	*Alloteropsis semialata*	*Chrysopogon fallax*	*Triodia bitextura*	*Sorghum intrans*
0-10	-	-	4/7	-
10-20	2/2	-	2/2	-
20-30	7/7	0/5	4/4	-
30-40	3/4	1/2	3/3	-
40-50	3/4	1/6	3/3	-
50-60	2/2	3/3	2/3	-
60-70	8/8	6/6	3/4	-
70-80	8/9	8/9	4/4	-
80-90	8/8	8/9	8/8	1/1
90-100	3/3	7/7	4/9	43/46
total (/47)	44	34	37	44

2.2.3 Other spatial data

The distance to water measurement was derived from a map of the distance of each pixel to permanent water sources. Permanent water was taken from the known waterholes in the study area and the Edith River (Figure 10). A spatial layer of the distance to known nests was also provided (Figure 11). Classifying pixels as either run-on (water receiving) or run-off (water shedding) was achieved using the distance to drainage lines. Any pixels less than 200 metres from a drainage line were considered run-on pixels and therefore allowed different timing of seeding onset than in run-off pixels (Figure 12). This drainage was not used as a measure of water available as the water present in these pixels is highly seasonal. Many of the habitat requirements of the Gouldian finch are determined by the two broad habitat types of the study area. The flat areas in the study area provide early wet season seed resources through the presence of drainage lines, while the rocky, rugged areas are the location of nesting sites and the rocky substrate prevents seeds burrowing and being lost as a food resource through the dry season. These areas therefore provide the location of dry season seed banks. The classification of pixels as either flat or rocky/rugged was achieved using a measure of ruggedness, which was calculated as the difference in elevation between adjacent pixels. Any value for a pixel greater than five was considered rocky (Figure 13).

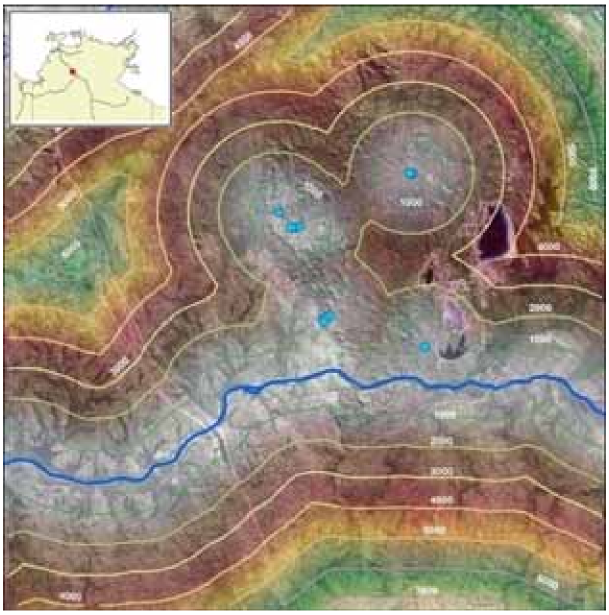


Figure 10. Distance to permanent water in the Yinberrie Hills study area.

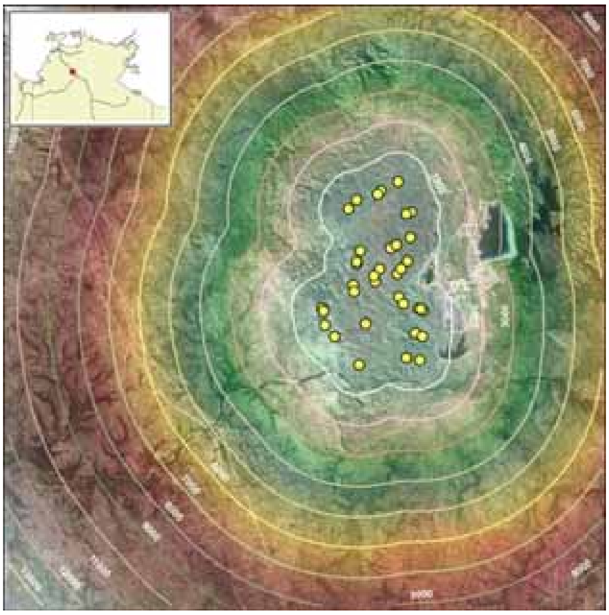


Figure 11. Distance to known nest sites in the Yinberrie Hills study area.

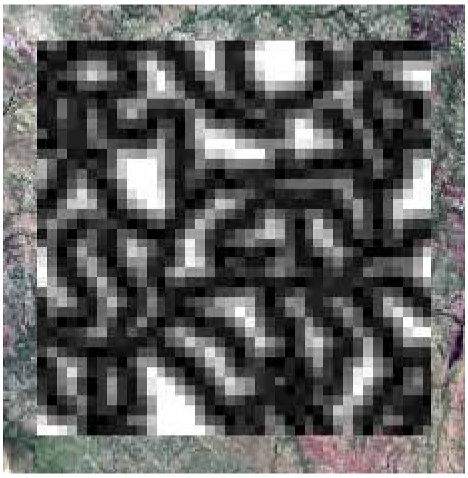


Figure 12. The distance to drainage lines used to classify pixels as either run-on (black) or run-off (white).

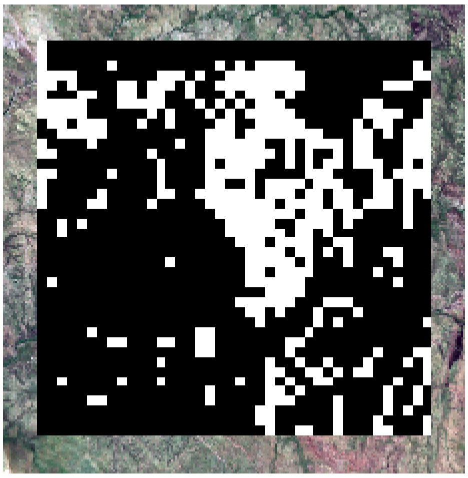


Figure 13. The classification of pixels as flat-lowland (black) or rocky-rugged (white) using a measure of ruggedness derived from differences in elevation of adjacent pixels.

2.2.4 Temporal analysis

It is realised that fine-scale temporal information is important for Gouldian finch management. For example, the period of time where seed resources are scarce is critical, and could be missed if a long time interval is specified (e.g. years). For this reason a temporal analysis of a single point in space (specified by latitude and longitude) is provided in the model. This analysis can be performed at a fine time-step (down to a single day) and provides an ASCII, tab-delimited output file of any node state specified by the user for detailed analysis. The time-step used by the model is specified during model setup and can be any increment with the period specified as days, weeks, months or years (e.g. 3 weeks). This option was provided to reduce the computational demand when using large raster spatial layers and could, for example, produce an annual habitat suitability layer on a given date.

2.2.5 Tracking rainfall

The timing, duration and volume of rainfall are important drivers of many ecological processes in northern Australia such as plant phenology (i.e. germination, growth, flowering, seeding and senescence/dormancy) and the availability of water. These factors are important determinants of habitat use by fauna such as the Gouldian finch.

The Gouldian finch Management System tracks rainfall using historic, daily rainfall records. The model performs a spin-up by reading all rainfall records up until the specified start of the simulation. This ensures that the time since last storms, annual wet reason rainfall and the amount and date of last rain is known at the start of the simulation based on actual data for the year being simulated. Best guess defaults are used if the simulation commences at the start of the rainfall records.

Time since last rain and time since the first storms of the wet season (measured in weeks) are used as surrogates in the model to provide a number of factors such as life stage of grasses, season and availability of water etc. Allowing the model to use this measure meant it was able to respond to rainfall variability, a superior approach than if static dates were used to specify the commencement and conclusion of the wet season.

2.2.6 Fire

Fires frequently occur in the northern savannas either as management burns or wildfires and are considered critical in defining habitat suitability and the landscape use by the Gouldian finch. This is because fire has the ability to dramatically alter grass biomass, species distribution, seeding onset and seed banks (e.g. Norman 1969; Mott and Andrew 1985; Crowley and Garnett 1999, 2001; Russell-Smith *et al*. 2003). Fire is included in the model as a series of spatial layers each with a given date of burning and other fire descriptors. Fires occurring in the wet and dry season have different influences on the grass species and seed resources. The process-based component of the model tracks the date of last fire for every pixel in the simulation. This is used to determine whether a grass species has recovered from fire and will produce seed. A problem with allowing user defined time intervals between model outputs is that a series of fires may occur between steps. The model currently does not consider all fires in a time step but only the most recent fire for a pixel. Therefore, currently the model considers no impact of repeated fires on grass seed production.

It is up to the user to supply fire regimes to the model whether based on actual fire maps or hypothetical fire management. The model assumes that the entire pixel is burned by the fire.

Wet season fire.

A wet season fire occurs after the first rains of the wet season when grasses have germinated. The BBN states that wet season fires affect expected grass abundance (i.e. reduction from potential), seed banks and seed on plant (i.e. available food resources). The fire type is defined by the user when a fire is added to the model. There is no error checking to ensure that the date of a wet season fire is within acceptable range. A wet season fire is considered if (a) the fire timing is set to WetSeason, (b) the fire date is after the first rains date and (c) the fire occurred less than a year ago (i.e. the fire has affected the current growth and seed production).

Dry Season fire

A dry season fire occurs during the dry season and currently only influences the amount of seed available to birds by ensuring the seed bank is more accessible. Dry season fires will also influence grass species that take a specified time to seed after fire. For a dry season fire to be included in the BBN it must (a) be less than a year since the fire and (b) not into the current wet season (i.e. after first storms date and less than 2 months from the first storms date).

3 RESULTS

A number of model simulations were performed to initially validate the model logic and investigate model behaviour. These preliminary findings are intended to provide proof of model functioning and explore some of the interactions between Gouldian finches and landscape processes. We will also use these model simulations to make some comment of the optimal fire management for Yinberrie Hills and future use of the model.

All simulations were performed for the study site at Yinberrie Hills (Figure 6) and the parameter values used can be found in Appendix A - Model Parameters. The simulations were performed using historic daily rainfall records collected at the Edith Falls Ranger Station (approximately 20 km east of the centre of the study area) as this was the closest measured daily rainfall to the study site. Average monthly and annual wet season rainfall measures were taken from the Bureau of Meteorology website (http://www.bom.gov.au) for Katherine. Simulations were performed during the period from July 1994 to July 1997, primarily the 1994-1995 wet season, for direct comparison with published findings and expert experience (Dostine et al, 2001).

3.1 Tracking rainfall

A number of node states in the Bayesian Belief Networks rely on classification of the season at the time of calculation. As it was considered critical that the model could capture the dynamic nature of seasonal rainfall, it was not sufficient to use calendar dates to delineate the season. It was therefore important that the temporal rainfall tracking component of the model could provide the current timing. Figure 14 shows the daily rainfall records for the Edith Falls Ranger Station and the seasonal classification by the model in the top horizontal bar. Rainfall was considered the best means of determining season as it delineates the wet and dry season. Initial storms (or cumulative rainfall) were used to trigger the start of the wet each year and this was considered to continue while rainfall was present. Once rainfall stopped, a count of time since the last rain event commenced to provide the “rain just stopped” and “wet finished” categories. While the categorised values were used for some nodes a continuous measure in weeks since first storms and since last rainfall was used for other nodes such as phenology allowing a better categorisation of these nodes. This model component was also able to capture the anomaly rainfalls that caused an early start to the wet season followed by a period of dry before the wet fully started as witnessed in August 1996.

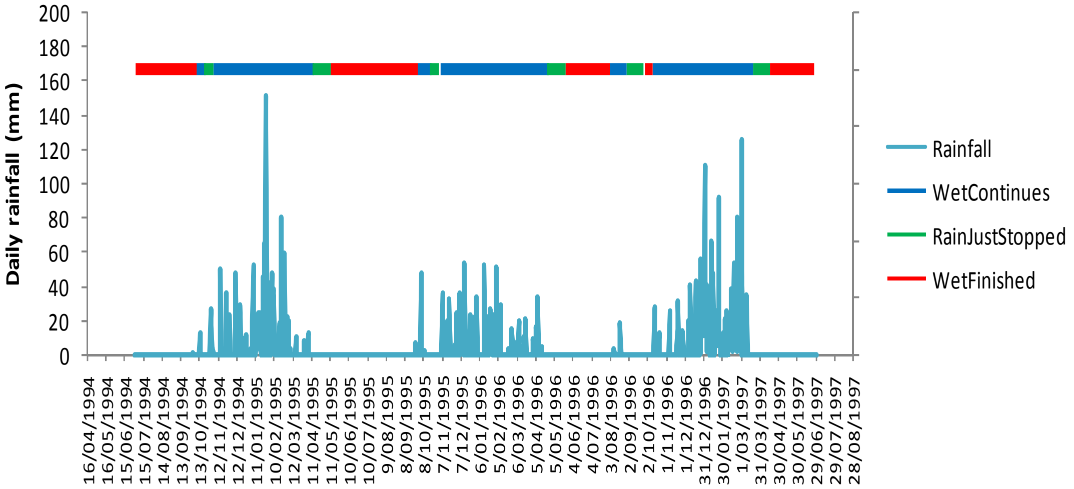


Figure 14. Calculation of the derived season (using weeks since last storm where blue indicates raining, green where rain stopped and red is dry) in the top bar and daily rainfall at Edith Falls Ranger Station for the period 1994-1997.

3.2 Temporal seed availability

A lowland, flat land unit location and a rocky, rugged uplands location were selected and simulated to investigate the temporal dynamics of seeds in the model. The two habitats were chosen to display the different seed bank dynamics during the dry season between the two areas. Figure 15 shows the lowland flat habitat simulation for just the 1994-1995 wet season and the period 1994 to 1997. The different seed timing of the grass species based on time since first storms is evident with *Alloteropsis semialata* first to flower and set seed, followed closely by *Chrysopogon fallax*. At completion of seeding and seedfall this seed source is lost to the birds providing a gap is seed resourced until *Triodia bitextura* seeds. There is then a larger period with no seed before the *Sorghum intrans* seeds in March. The habitat suitability measure is provided as the blue diamonds. The probability is below one while the perennial species seed as the selected pixel was classified as marginal with respect to its distance to permanent water. As *Sorghum intrans* seeds after the breeding season commences, and the pixel was classified as distant to nesting sites, the habitat suitability is low in March even though abundant Sorghum seed is available on the plants. The effects of an early wet season onset are seen in the 1995-1996 wet season (Figure 15b) where there is an early seed set with *Alloteropsis semialata*.

Figure 16 provides the temporal seed dynamics for the four grass species for a pixel located in the rugged, rocky, upland areas. The differences between the lowland flat site and the rocky upland site are shown. This site was classified as optimal with respect to distance from permanent water and so habitat suitability is high whenever seeds are available. This pixel is also close to nesting sites, and so, there is good habitat suitability when sorghum seeds. Being in the rocky uplands, *Sorghum* seed persists in a seed bank after seed fall, but is subject to decay through the dry season as shown by the stepped decline in the probability of abundant seed (and a corresponding increase in limited or no seed). The less than optimal probability of *Alloteropsis semialata* and *Chrysopogon fallax* is due to the method of assigning grass presence probability using the probability of the species being present in the pixel (from the distribution models) and the fact that these species were not highly probable, unlike *Sorghum*.

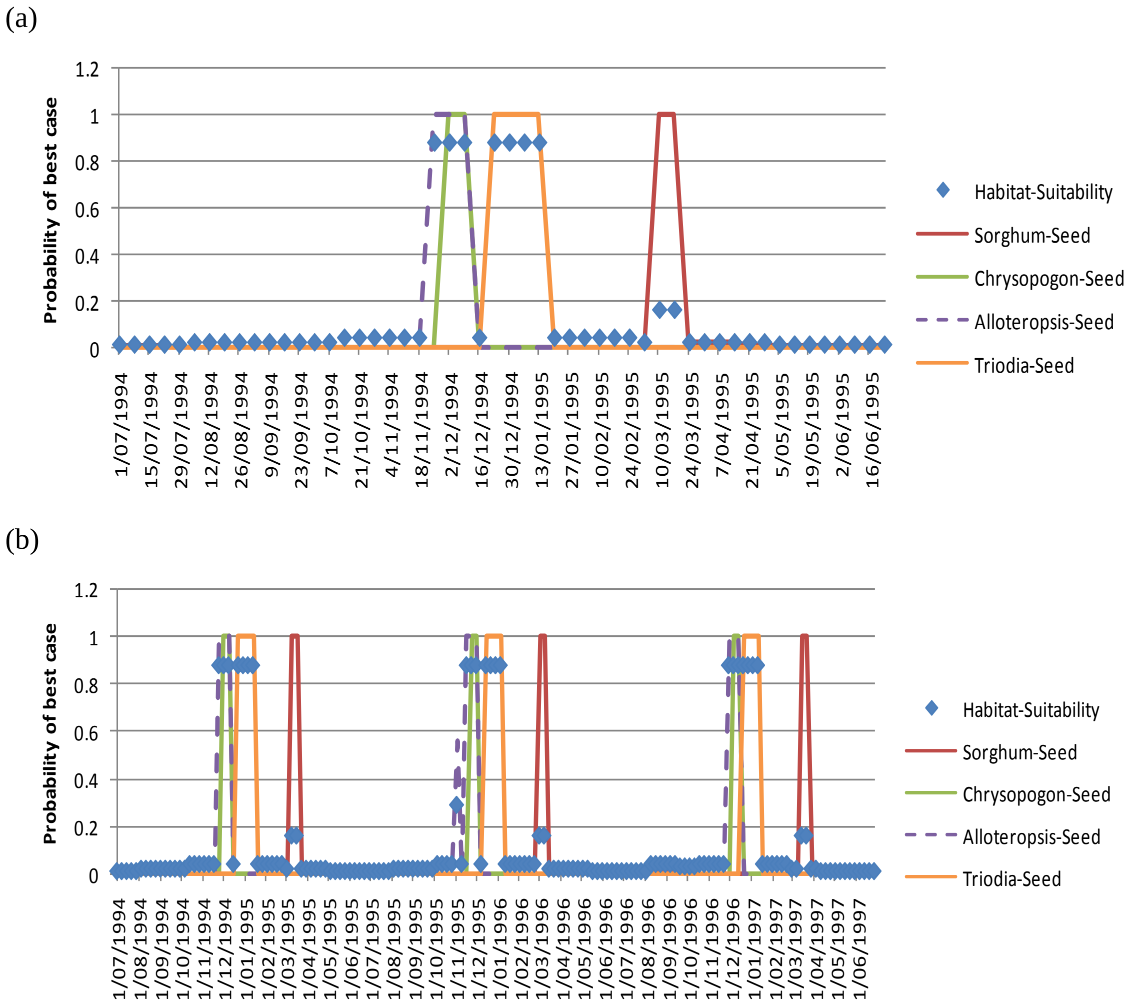


Figure 15. The predicted probability of the best state of grass seed abundance (abundant) for the four grass species *Sorghum intrans*, *Chrysopogon fallax*, *Alloteropsis semialata* and *Triodia bitextura* and overall habitat suitability for a pixel located in a flat lowland for the period (a) 1994-1995 wet season and (b) July 1994 - July 1997.

3.3 Spatial seed availability

While the previous analysis of temporal seed availability provides fine temporal scale detail, it can only provide the dynamics of a single cell. To incorporate the spatial variability in grass species distributions, water availability, topography and nesting locations simulations encompassing the study area were required. The spatial distribution of the probability of high seed abundance is provided for each species through the 1994-1995 wet season in Figure 17. The different species' phenology is evident in combination with the grass species distributions. The fine speckled effect seen in March 1995, November 1994 and December 1994 for *Sorghum intrans*, *Chrysopogon fallax* and *Triodia bitextura* respectively is the result of early seeding in run on cells as a result of good water availability. While there is often good seed availability of one species during the wet season this analysis shows that there are periods with no seed, or seed bank (20th Jan – 17th Feb) before the seeding of *Sorghum intrans*.

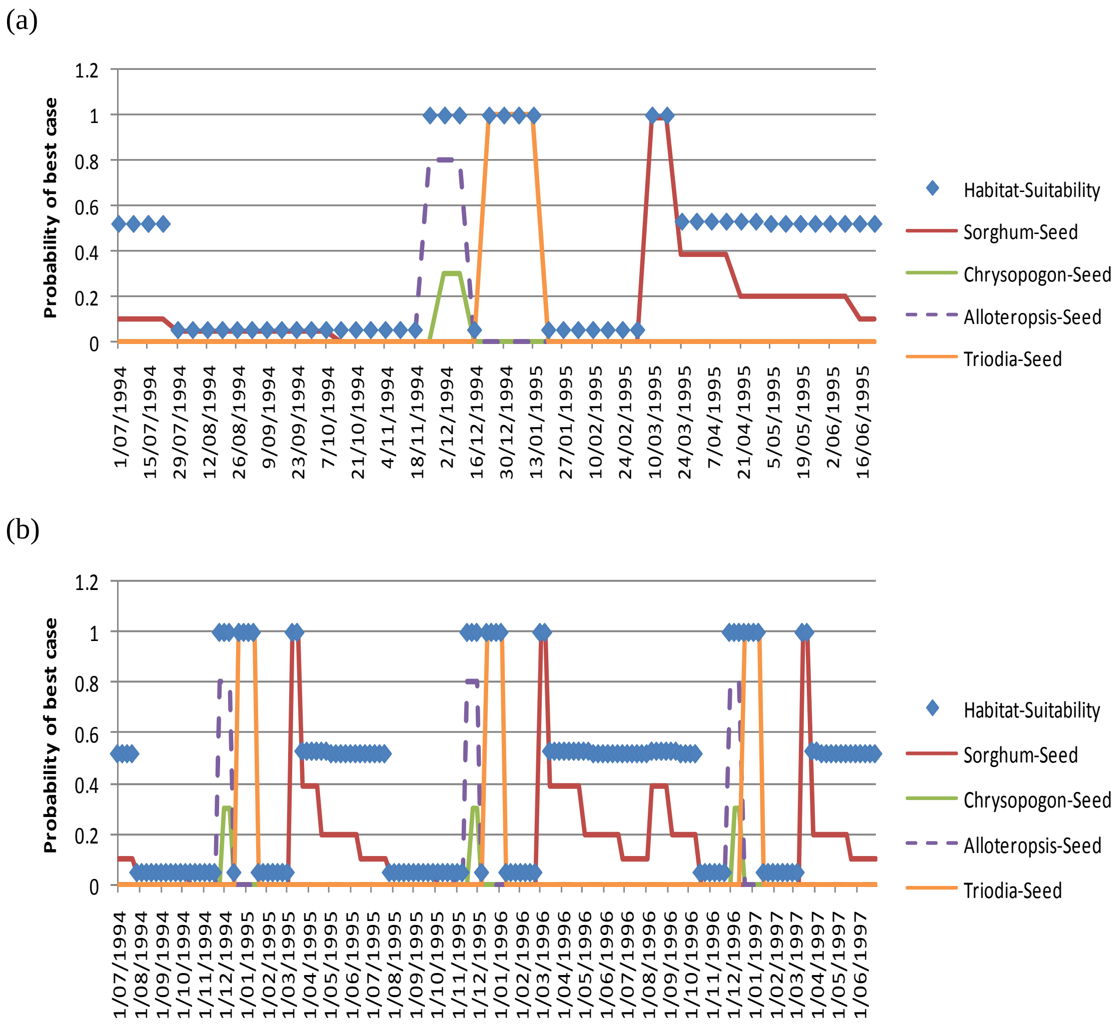


Figure 16. The predicted probability of the best state of grass seed abundance (abundant) for the four grass species *Sorghum intrans*, *Chrysopogon fallax*, *Alloteropsis semialata* and *Triodia bitextura* and overall habitat suitability for a pixel located in a rugged, rocky uplands for the period (a) 1994-1995 wet season and (b) July 1994 - July 1997.

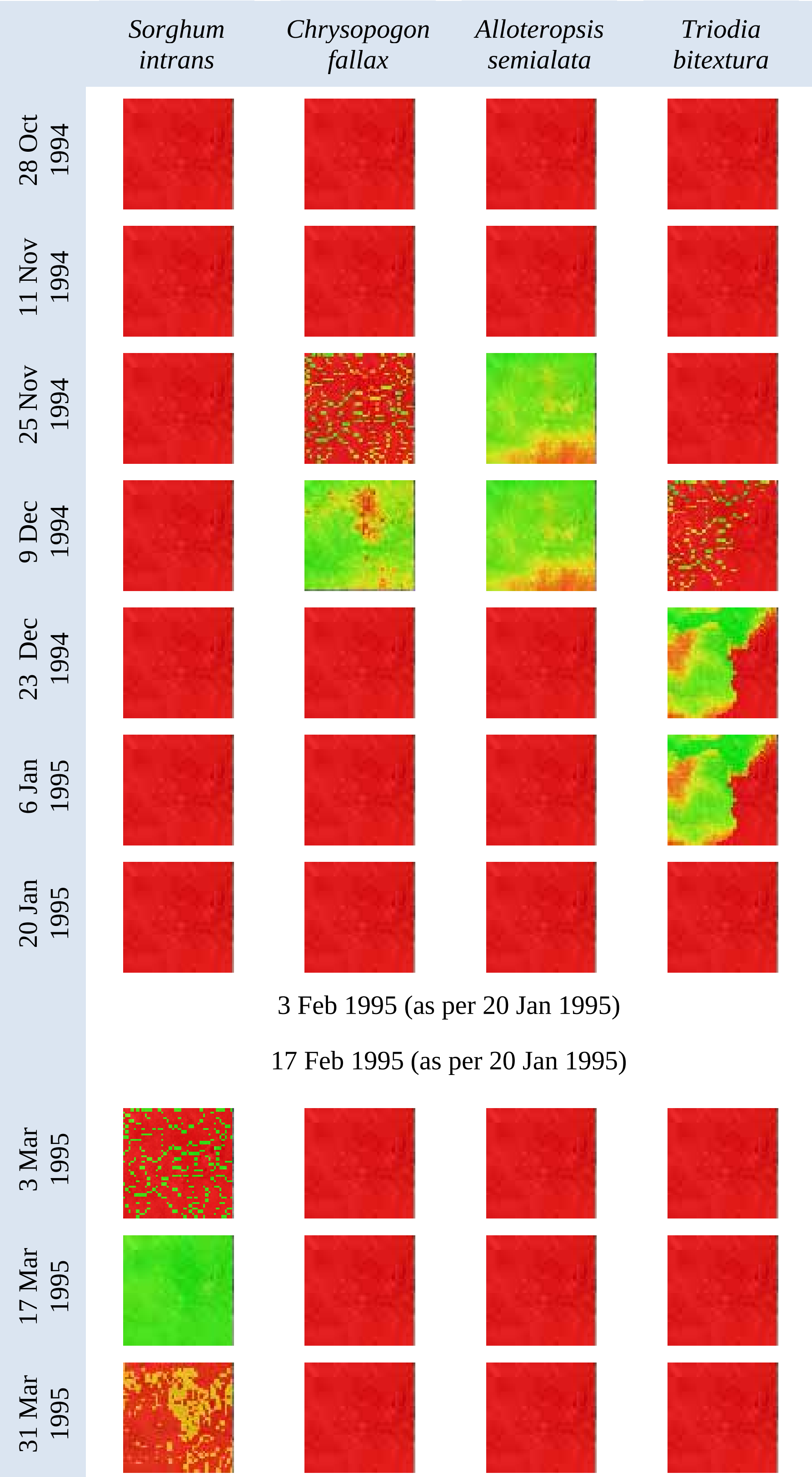
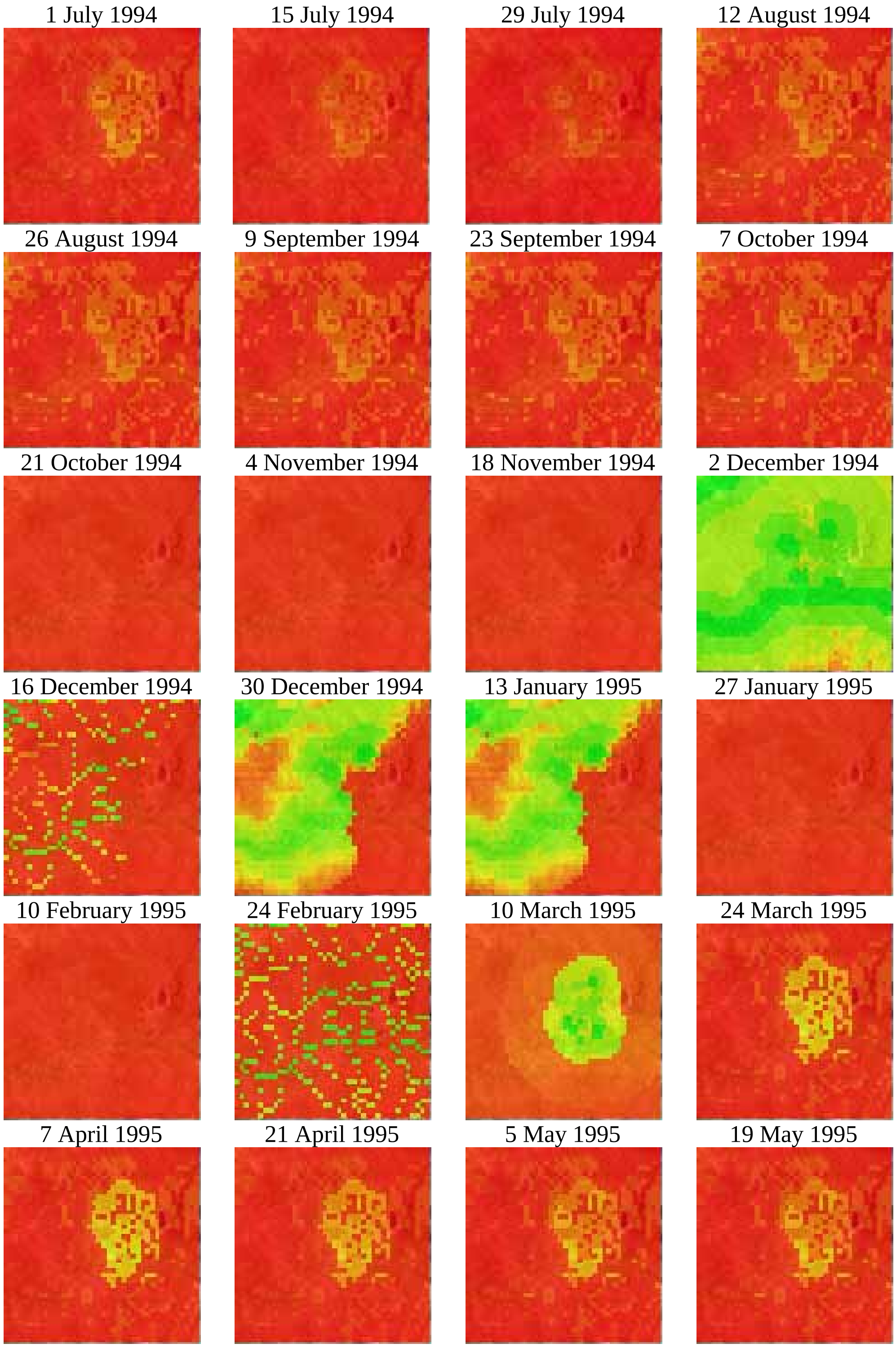


Figure 17. Fortnightly predicted probability layers of the highest state of seed abundance (abundant) for the four grass species considered at Yinberrie Hills from 28 October 1994 to 31 March 1995. Red = 0/absent, Yellow = 0.5, Green = 1/abundant.

3.4 Habitat suitability

The simulations previously presented have only involved the use of the individual grass species BBNs. To provide maps of habitat suitability through time required linking these BBNs to the habitat suitability BBN. The probability of good habitat conditions for Gouldian finches is provided in Figure 18. This figure shows the fortnightly habitat suitability layer from the 1st July 1994 through to the 19th May 1995. It is evident that much of the Yinberrie Hills study area is of poor suitability for the majority of the year. This is because the birds rely on the *Sorghum* seed bank through the dry season that only persists in rocky upland areas and is lost when the first rains cause germination. While Figure 17 shows abundant Sorghum throughout the study area in early march, the commencement of breeding results in a restricted area of suitable habitat. This region, close to nesting sites, influences the habitat suitability layers until the end of July the following year when breeding stops and the rocky upland areas previously too distant from nests become available. A critical seed nadir is evident during the wet season as the birds prepare for breeding (February) as shown in the 27th January and 10th February maps.



1 July 1994
15 July 1994
29 July 1994
12 August 1994
26 August 1994
9 September 1994
23 September 1994
7 October 1994
21 October 1994
4 November 1994
18 November 1994
2 December 1994
16 December 1994
30 December 1994
13 January 1995
27 January 1995
10 February 1995
24 February 1995
10 March 1995
24 March 1995
7 April 1995
21 April 1995
5 May 1995
19 May 1995

Figure 18. The fortnightly predicted habitat suitability of the Yinberrie Hills study area for the 1994-1995 wet season period based on the probability of habitat suitability being in the abundant state. Red = 0/poor, Yellow = 0.5, Green = 1/good.

3.5 Effects of fire

All simulations performed to this point have not been influenced by fire, but fire must be considered one of the most important landscape processes affecting Gouldian habitat suitability.

The habitat suitability simulation performed in Figure 18 was repeated with two fire extents, complete site and a 33% fire scar (Figure 19), and with different timing of fires (Figure 20). These fires were dry season ignitions typical of management burns in Yinberrie Hills and therefore did not include the wet season fire effects built into the model.

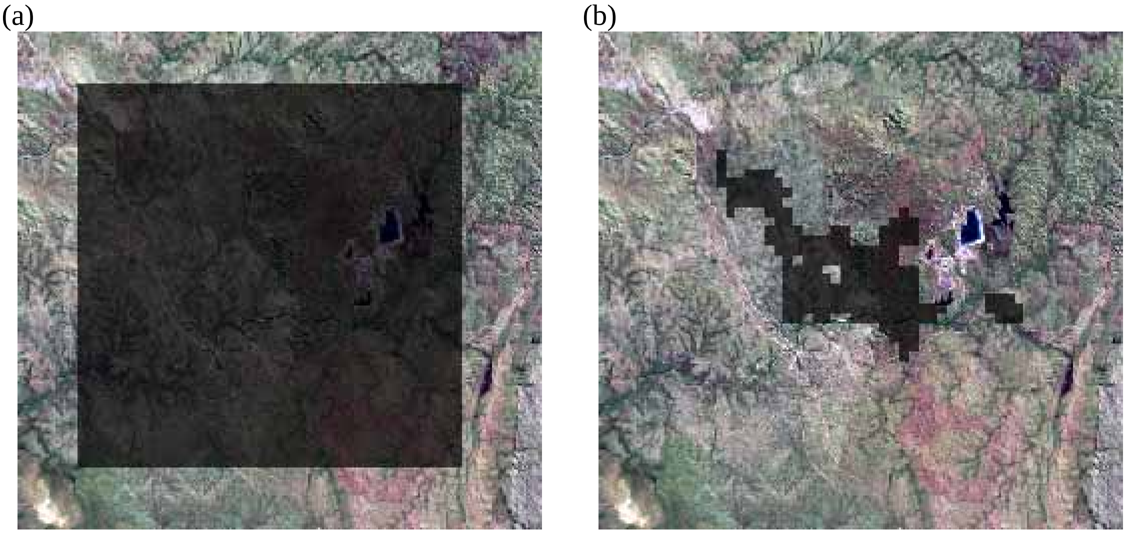


Figure 19. Location of the fires used showing (a) the whole study area fire and (b) a fire scar that burned 33% of the study area.

As the simulated fires were all dry-season ignitions, the main effect of these fires was to increase the seed bank availability through the removal of grass biomass and exposing seeds to birds. This is shown in Figure 20 where there is an immediate increase in habitat suitability from the date of the fire. The size of the fire (whole site versus 33%) affected the extent of the habitat suitability improvement. The early April fire provided the greatest benefit as there was seed available (prior to dry season decay) and the effect was observed for the entire dry season. Any effect of dry season fire was removed upon first rains heralding the beginning of the wet season.

While the dry season fires initially appear beneficial to Gouldian finch habitat suitability, they can have consequences during the following dry season as shown by the row corresponding to the 23rd December 1994. This is because some grass species such as *Triodia* sp will not recover and seed for a number of years after a fire (3 years in these simulations). Thus, the whole site fire removes this valuable seed resource and the 33% fire removes the seed from the fire scar area. The model currently assumes there is no effect on the other grass species that are dormant and assumed to grow upon first rains and once again produce seed.

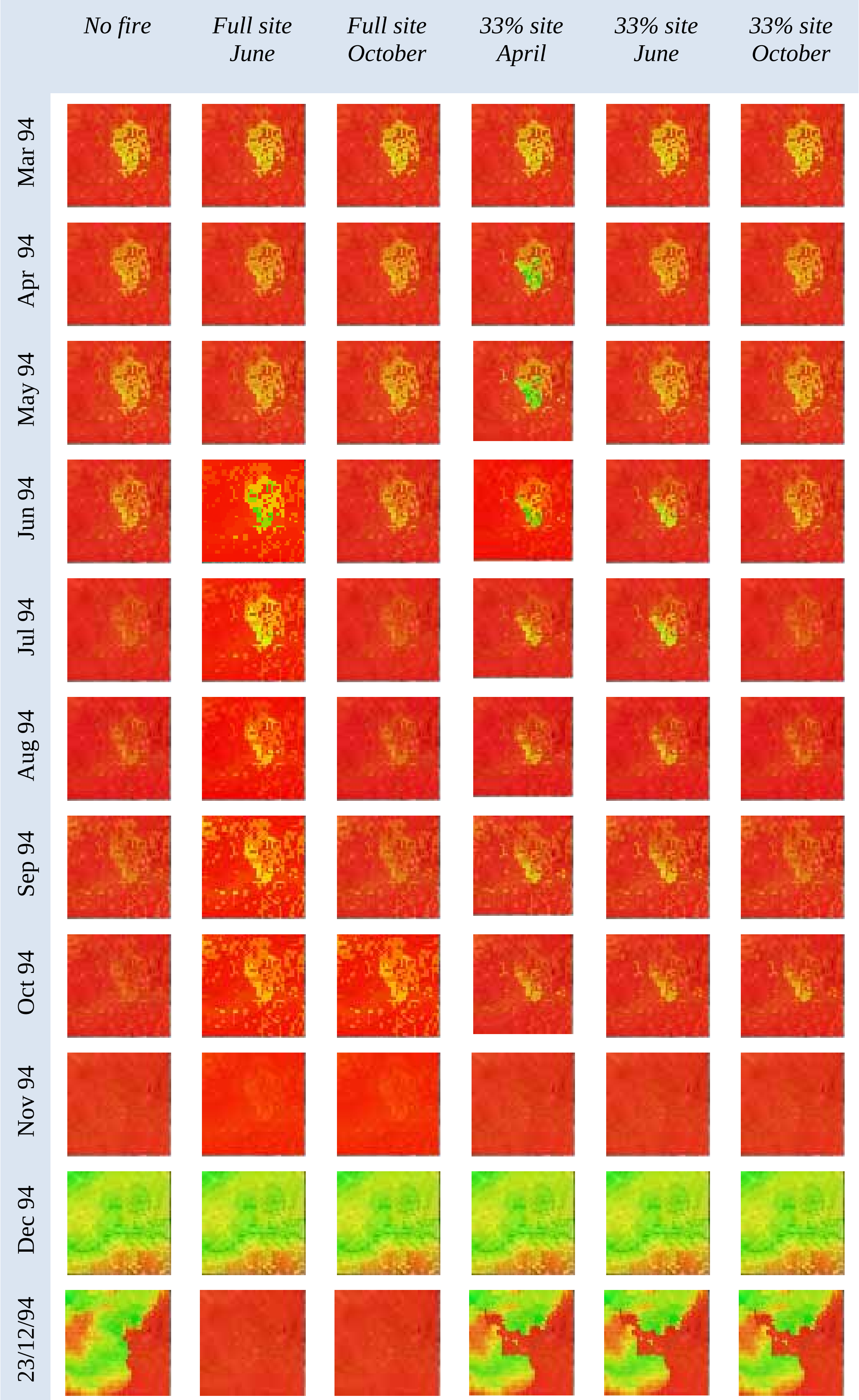


Figure 20. The effect of the various extents (whole site and 33% fire scar) and timing (April, June and October ignitions) of simulated fires on Gouldian finch habitat suitability during 1994.

4 DISCUSSION

Any model is a simplified representation of reality. They can never be expected to provide an exact representation of reality because of natural system complexity and the limitations of our current understanding and available data. This project aimed to develop a model capable of assimilating the current knowledge of the Gouldian finch to determine the likelihood of habitat suitability. In doing so it provides a means of exploring the consequences of management on an elusive, threatened species where changes in habitat suitability and population processes my not be immediately visible to land managers.

4.1 Findings and management implications

This project highlights that while we may understand the processes important to a granivorous bird species, the natural, spatial and temporal variability in a landscape combined with a management overlay make a full system understanding difficult to synthesise. A computer modelling framework capable of integrating knowledge and available data with management scenarios to provide likely outcomes is a valuable research and management tool. Firstly, it reveals how successfully our understanding captures the species and system processes, exposing knowledge gaps and new areas to consider. Secondly, it provides a prediction of the likely outcomes of various management options such as burning and grazing and alludes to the factors important in the system, which should be preserved to maintain optimal habitat for the given species.

The predicted habitat suitability maps show that food is predominantly the limiting resource when determining habitat suitability for Gouldian finches. As the habitat suitability is an index we acknowledge that the colour scale presented could influence the appearance of the maps. However, this does not influence the relative spread of values and is not the case in this project as the on or off nature of many of the model nodes suggests a boom-bust style of food resource availability for the birds. In the absence of fire, a reliable source of food is guaranteed each year while seed is on the plant. The *Sorghum* seed bank and access to rocky areas where the seed remains available through the dry season ensures there is always seed and as it turns out, close to nesting sites. Loss of seed through consumption and decay means this seed bank is not a readily accessible supply of food and the presence of dry season fires can improve seed accessibility. Unlike other finch species, the inability of the Gouldian finch to switch to non-seed resources increases the importance of reduced seed availability predicted by the model.

This study also explains why Yinberrie Hills currently supports populations of Gouldian finches and what landscape characteristics would lead to similar habitats elsewhere. The requirement of breeding with access to trees with hollows and restricted movements reduces the available area to forage for seeds between February and August each year. Yinberrie Hills supplies breeding sites in close proximity to rocky areas, which provide a Sorghum seed bank with access to water.

One difficulty in disseminating the results of complex system models to a varied audience is providing concise and useful output and data summaries. In this study we have provided a series of spatial maps to indicate the likely state of habitat suitability during the year. The spatial map was considered the easiest to interpret given the amount of data to display. These snap shots are useful but often miss the fine scale dynamics of the system between time steps, which may be critical. Often a user will require detailed output to determine the reason for model outcomes. This model provides the ability to output state value data, from each BBN, for each time step, which can be further analysed. This allows a more detailed analysis of any management options. In order to assess a quantitative difference in habitat suitability between two runs with different management, the spatial and temporal aspects of the simulations need to be combined into a single index or measure. This is not a trivial task. We would expect that a suitable site for finches would have some (or good) seed abundance in areas near water and close to nesting during the breeding season. Areas of poor habitat suitability are not necessarily critical if alternatives are available. Therefore, a simple measure of the best value for a pixel through the run is not sufficient. We would require a measure of the time when the system was not suitable for finches, representing the time when birds would be under increasing stress. At present the series of maps is our best indication of overall suitability.

This model can highlight the future impacts of fire management on the habitat of Gouldian finches. The initial results show how a fire may be beneficial in the first dry season, but have consequences for seed production during following wet seasons. It also shows areas that should be protected, and how large scale (whole of site) fires may be most detrimental. We can comment on the optimal fire regime for Yinberrie Hills as it would not include extensive, whole of site fires, be mindful of the recovery time of important species such as *Triodia bitextura* and ensure burning resulted some improvement of seed availability close to nesting areas. Of course this information must be incorporated with managers' knowledge of fuel management requirements, ignition sources such as roads and the additional ecology of the direct effect of fire on nesting birds and nest trees. This shows that the overall system knowedge captures in this version of the model is limited to grass dynamics and some landscape details. Future versions may need to consider additional aspects of the Gouldian finch ecology.

The next step in the use of this model is to undertake rigorous analysis and validation of predicted outcomes with field data and expert understanding. In doing so we will further identify weaknesses in our understanding of this species and aspects of the landscape important for the persistence of the species. There are also a number of additions that the model would benefit from having included that will now be discussed.

4.2 Model limitations and future directions

During the development of the model a range of aspects were considered but not included in the model due to the available development time. The following aspects should be added in future to improve the model:

- There is no ability for Gouldian finches to feed on newly germinated *Sorghum* seeds as reported by Lewis (2007). This food source is currently not included in the habitat suitability index. After seed germination the model shows a loss of food resources and not an increase in nutrient rich shoots.
- There is no dynamic breeding season length or onset based on resource availability. Currently breeding (e.g. pre-breeding, nesting, fledging and end of breeding) is specified with calendar dates. The important aspect is the start of breeding and the end of breeding as this specifies when distance to nests and location is important for the finches. Future

versions may benefit from a process based method of determining breeding season timing but this requires more information on finch ecology.

- There is no means of simulating variability in rainfall across the study area. The current model allocates the daily rainfall records to all pixels simulated. There is no way of providing spatial variability in rainfall from localised storms. This spatial heterogeneity of initial storms happens at a scale finer than the 20km x 20km study area and results in a spatial and temporal mosaic of seeding that the finches can utilise. Ideally, every cell would have its own rainfall details (much like time since fire). However, this requires a method of applying stochastic rainfall patterns to the site that would result in the need to simulate multiple runs to capture the variability.
- There are currently no species distribution layers available for other grass species such as *Heteropogon triticeus* and *Themeda triandra.* Some grass species not considered in this project may not occur in great abundance, but may be very important sources of seed during the periods shown by the model to have low seed resource when only considering the dominant four species.
- There are no dynamic grass population processes. At present the model uses the grass distribution layers provided and there is no change to the presence, absence or biomass of grass during the simulation. It is known that grazing and particular fire regimes have the ability to change the grass abundance and distribution that will have flow on effects to finch habitat suitability. This would be a valuable addition to the model to capture temporal change in landscape function with disturbance and management.
- Current simulations have not included the impact of grazing as grazing pressure data was not available.
- The model is not currently written with CPU threading. This means that while the model is running, the GIS environment is not available and some screen refreshing may not occur. A thread safe version would allow the simulation to be aborted by the user and provide a complete front end interface.

4.3 Applicability to other sites and species

The modelling described in this report is specific to one site, and one threatened species. This singularity matched the explicit objective of the project. But it will substantially constrain the value of this project if it cannot also provide some insights or foundation for other locations and other species. In this section, we consider broader application.

Essentially, the steps in this study were:

- for a circumscribed study area, identify the critical resources required for this threatened species;
- describe the variability (in time and space) of these resources, and the factors that influence this variability;
- incorporate this information into a modelling framework, using Bayesian Belief Networks (BBN);

- match the Bayesian models with a Geographic Information System (GIS) in order to display the results, showing spatial and temporal variation in resources;
- use this system manipulatively (to attempt to predict resource responses under a range of management scenarios).

The novelty of the approach used here comes from the 3rd, 4th ad 5th steps above, and particularly in the linkage of a BBN approach with a Geographic Information System. In this project, we demonstrate that such linkage is possible and productive, and the modelling developed for this project now provides a good foundation for many other ecological and management situations.

In the highly seasonal environments of northern Australia, many resources show spatial and temporal variations in resources, in a manner comparable to that considered in this project for Gouldian finches at Yinberrie Hills. Such resource variation is critical in the ecology and survival of many threatened species, and management of such species may be most effective when it can understand and appropriately manipulate such resource variation. The system developed here provides a tool to help this understanding and manipulation.

The model developed here will be most readily applicable to the management of Gouldian finches at other locations, because much of the information in the BBN will be directly relevant – e.g. at other sites than Yinberrie Hills the same grass species may still be critical food resources for Gouldian finches, and may show similar phenological patterning, and response to fire (or other management factor). Some additional work would be required to (1) develop GIS layers (notably in the distribution of grass species), (2) include in BBN models information about the phenological and other patterns for any additional grass species that may be locally important, and (3) include in the BBN models any management information that was different from the Yinberrie area. But the work required to incorporate these steps is relatively trivial. Indeed, we intend to attempt to adapt the Yinberrie model to another important Gouldian finch location, at Mornington station in the Kimberley, later in 2009, in collaboration with Sarah Legge (Australian Wildlife Conservancy).

We can also apply the model developed far more broadly than simply other Gouldian finch sites. The extent of work required will become increasingly more substantial as the resource characteristics for other situations differ more markedly from that of the grass species used in the Yinberrie model (e.g. it may be more challenging to extend the model to include fruit resources that may vary over years depending upon shrub size, or to include hollow logs that may decay or be consumed by fire). Thus the model will be easiest to adapt to the consideration of comparable ecological situations, such as other threatened species that use grass seeds and where the abundance of these seeds may be affected by fire or grazing. Nonetheless, so long as there is sufficient information available to describe the critical resources for a threatened species and the spatial and temporal pattern of the abundance of those resources, then the type of modelling used here can build from or be developed from the approach used in this project.

The understanding and model details can be further refined with new information and data. It can be used predictively (and such prediction can be tested in order to more fully gauge the success of the model, or to refine it), by field-testing, for example by sampling to consider whether the Gouldian finch (or other threatened species considered) is in fact preferentially using the locations that the model considers is optimum at any given time. Such testing may provide further feedback, for example by possibly indicating critical resources that were not considered as critical initially in the model.

At this stage, the model considers only the immediate responses of grass species to any fire, rather than recognising that the abundance of grass species (and hence floristic composition) may show longer-term variation in response to many years of fire regimes. The present version of the model can be refined further by introducing the ability to handle longer-term consequences of fire regimes.

4.4 Conservation management in a changing environment

The development of this model is based on previous research at Yinberrie Hills and uses historic (up to present) rainfall records. Therefore, the simulations and management options provided assume a relatively reliable system operating within known bounds. This assumption may no longer be valid with rapidly increasing changes in climate being experienced worldwide.

While this model cannot predict the future of the Gouldian finch populations, it can provide us with valuable insights into likely changes in habitat suitability with climate change and the chances of Gouldian finches adapting to these changes. The results of this project show that Gouldian finches currently persist in a difficult environment where food resources are often limited or almost inexistent. They have evolved to live in a variable environment by tracking suitable patches in a heterogeneous landscape, but may not cope with further changes. It may be that climate change to date has led to the threatened status of the species and we are observing current responses to a changing landscape.

In this project we have seen that the seed resources are extremely temporally and spatially dynamic. We would expect that changes in climate in the savannas will increase the extremes of rainfall (greater dry seasons, more rain in the wet season) and temperature (extreme heat days) and this will directly influence grass dynamics and the ecosystem relying on grass resources. At present the global climate models predict future rainfall amount, but are unable to comment on the future temporal and spatial distribution of rainfall. From what is being experienced elsewhere, we would expect that even slight shifts in the timing of the wet season will result in altered dry season length. Located 300 km away from the strongly monsoonal wet season of the coast, the Katherine region of the Northern Territory would be expected to experience greater variability in weather than currently seen. This could result in a seed nadir, which the granivorous Gouldian finch cannot cope with. Also, fire weather conditions may result in more extensive fires, which burn the entire study site, regardless of management efforts, thus causing the altered seed abundance reported in this project. In this case the Gouldian population must be able to access suitable areas outside the Yinberrie Hills study area. This model can help us explain the system, but further field based analysis is required to better understand grass responses to changing weather and fire regimes and the resulting impacts on the Gouldian finch.

Land managers have to include a lot of understanding of the consequences of their actions to ensure sustainable management. Often this detailed understanding is outside their area of expertise. This is the reason this decision support tool has been developed. The benefit of a model is that we can also use it to test our understanding outside the bounds of current experiences. We can use the model to test known fire effects, or simulate fire scenarios.

Likewise, we can use actual rainfall records or predict habitat suitability with synthetic rainfall data representing possible future scenarios. Therefore, the building of models with out current understanding may be a powerful tool for learning what to expect and preparing to adapt to future climate changes. A combination of modelling approaches such as that used in this project and further field research is the best means of ensuing sustainable conservation management in the tropical savannas and elsewhere.

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6 REFERENCES

Bashari, H., Smith, C. and Bosch, O.J.H., 2009. Developing decision support tools for rangeland management by combining state and transition models and Bayesian belief networks. Agricultural Systems. 99: 23-34.

Bell, P.J. (1996). Survey of the nasal mite fauna (Rhinonyssidae: Kytoditidae) of the Gouldian Finch *Erythrura gouldiae* and some co-occurring birds in the Northern Territory. *Wildlife Research* **23**, 675-685.

Cain, J.D., Jinapala, K., Makin, I.W., Somaratna, P.G., Ariyaratna, B.R. and Perera, L.R., 2003. Participatory decision support for agricultural management. A case study from Sri Lanka. Agricultural Systems. 76: 457-482.

Crowley, G. (2008). Cockatoo grass *Alloteropsis semialata* as a keystone species in northern Australia. *Northern Territory Naturalist* **20**, 58-63.

Crowley, G., and Garnett, S. (1999). Seeds of the annual grasses *Schizachyrium* spp. as a food resource for tropical granivorous birds. *Australian Journal of Ecology* **24**, 208-220.

Crowley, G., and Garnett, S. (2001). Growth, seed production and effect of defoliation in an early flowering perennial grass, *Alloteropsis semialata* (Poaceae), on Cape York Peninsula, Australia. *Australian Journal of Botany* **49**, 735-743.

Dostine, P.L., and Franklin, D.C. (2002). A comparison of the diet of three finch species in the Yinberrie Hills area, Northern Territory. *Emu* **102**, 159-164.

Dostine, P.L., Johnson, G.C., Franklin, D.C., and Hempel, C. (2001). Seasonal use of savanna landscapes by the Gouldian finch, *Erythrura gouldiae*, and co-existing finches in the Yinberrie Hills area, Northern Territory. *Wildlife Research* **28**, 445-458.

Franklin, D. C., Whitehead, P. J., Pardon, G., Matthews, J., McMahon, P. and McIntyre, D. (2005) Geographic patterns and correlates of the decline of granivorous birds in northern Australia, *Wildlife Research* **32**, 399-408.

Franklin, D.C. (1999). Evidence of disarray amongst granivorous bird assemblages in the savannas of northern Australia, a region of sparse human settlement. *Biological Conservation* **90**, 53-68.

Franklin, D.C., Burbidge, A.H., and Dostine, P.L. (1999). The harvest of wild birds for aviculture: an historical perspective on Finch trapping in the Kimberley with special emphasis on the Gouldian Finch. *Australian Zoologist* **31**, 92-109.

Garnett, S.T., and Crowley, G.M. (1994). Wet season feeding by four species of granivorous birds in the Northern Territory. *Australian Bird Watcher* **15**, 306-309.

Garnett, S.T., and Crowley, G.M. (1995). Feeding ecology of Hooded Parrots *Psephotus dissimilis* during the early wet season. *Emu* **95**, 54-61.

Henriksen, H.J. and Barlebo, H.C., 2007. Reflections on the use of Bayesian belief networks for adaptive management. Journal of Environmental Management, 88(4):1025-1036.

Jensen, F.V. (2001). Bayesian networks and decision graphs. Springer, New York.

Lewis, M. (2007) Foraging responses of the endangered Gouldian finch to temporal differences in seed availability in northern Australian savanna grasslands. In *Temporal Dimensions of Landscape Ecology, Wildlife Responses to Variable Resources.* (Eds J.A. Bissonette and I. Storch.) pp. 218-235. Springer, New York.

Liedloff, A. C., and Cook, G. D. (2007). Modeling the effects of rainfall variability and fire on tree populations in an Australian tropical savanna with the FLAMES simulation model. *Ecological Modeling* **201**, 269-282.

Liedloff, A.C., Coughenour, M.B., Ludwig, J.A., and Dyer, R. (2001). Modelling the trade-off between fire and grazing in a tropical savanna landscape, northern Australia. *Environment International* **27**, 173-180.

Marcot, B.G. (2006). Characterising species at risk I: Modelling rare species under the Northwest Forest Plan. Ecology and Society, 11(2).

McNay, R.S., Marcet, B.G., Brumovsky, V. and Ellis, R., 2006. A Bayesian approach to evaluating habitat for woodland caribou in north-central British Columbia. Canadian Journal of Forest Research. 36: 3117-3133.

Michell, C., Price, O., Dostine, P., Lewis, M. and Woinarski, J. (Unpublished) Wet season resources for granivorous birds in a hilly tropical savanna in northern Australia. A report for Northern Territory Department of Natural Resources, Environment, The Arts and Sport. Darwin, Australia.

Mott, J.J., and Andrew, M.H. (1985). The effect of fire on the population dynamics of native grasses in tropical savannas of north-west Australia. *Proceedings of the Ecological Society of Australia* **13**, 231-239.

Norman, M.J.T. (1969). The effect of burning and seasonal rainfall on native pastures at Katherine, N.T. *Journal of Australian Institute of Agricultural Science* **47**, 132-141.

Norsys Software Corporation, 1998. Netica^{TM} Application for Belief Networks and Influence Diagrams: User’s Guide. Norsys Software Corporation, Vancouver, Canada.

Nyberg, J.B., Marcet, B.G. and Sulyma, R., 2006. Using Bayesian belief networks in adaptive management. Canadian Journal of Forest Research. 36: 3104-3116.

Nyberg, J.B., Marcot, B.G. and Sulyma, R. (2006) Using Bayesian Belief Networks in adaptive management. *Canadian Journal of Forest Research* **36**, 3104-3116.

Pollino, C.A., White, A.K. and Hart, B.T., 2007. Examination of conflicts and improved strategies for the management of an endangered Eucalypt species using Bayesian networks. Ecological Modelling. 201: 37-59.

Russell-Smith, J., Whitehead, P.J., Cook, G.D., and Hoare, J.L. (2003). Response of *Eucalyptus*-dominated savanna to frequent fires: lessons from Munmarlary, 1973-1996. *Ecological Monographs* **73**, 349-375.

Smith, C., Russell, I., King, C., 2005. Rats and rice: Belief network models of rodent control in the rice fields of Cambodia, in: MODSIM 2005 International Congress on Modelling and Simulation. eds A. Zerger, R.M. Argent, pp. 449-455. Modelling and Simulation Society of Australia and New Zealand, Melbourne.

Smith, C.S., Howes, A.L., Price, B. and McAlpine, C.A., 2007b. Using a Bayesian belief network to predict suitable habitat of an endangered mammal - the Julia Creek Dunnart (*Sminthopsis douglasi*). *Biological Conservation*. 139 (3-4):333-347.

Tidemann, S.C. (1996). Causes of the decline of the Gouldian finch *Erythrura gouldiae*. *Bird Conservation International* **6**, 49-61.

Tidemann, S.C. (1990). Relationships between finches and pastoral practices in northern Australia. In *Granivorous birds in the agricultural landscape*. (Eds J. Pinowski and J. D. Summers-Smith.) pp. 305-315. PWPN-Polish Scientific Publishers, Warsaw.

Tidemann, S.C. (1993). Management of a threatened species: the Gouldian finch example. In *Birds and their habitats: status and conservation in Queensland*. (Eds C. P. Catterall, P. V. Driscoll, K. Hulsman, D. Muir and A. Taplin.) pp. 123-131. Queensland Ornithological Society, Brisbane.

Tidemann, S.C. (1993). Where are Gouldian finches after the breeding season? *Victorian Naturalist* **110**, 238-243.

Tidemann, S.C., and Woinarski, J.C.Z. (1995). Moult characterisstics and breeding seasons of Gouldian, *Erythrura gouldiae*, Masked, *Poephila personata* and Long-tailed Finches, *P. acuticauda*, in savannah woodland in the Northern Territory. *Emu* **94**, 46-52.

Tidemann, S.C., Boyden, J., Elvish, R., Elvish, J., and O'Gorman, B. (1992a). Comparison of the breeding sites and habitat of two hole-nesting estrildid finches, one endangered, in northern Australia. *Journal of Tropical Ecology* **8**, 373-388.

Tidemann, S.C., Lawson, C., Elvish, R., Boyden, J., and Elvish, J. (1999). Breeding biology of the Gouldian finch *Erythrura gouldiae*, an endangered finch of northern Australia. *Emu* **99**, 191-199.

Tidemann, S.C., McOrist, S., Woinarski, J.C.Z., and Freeland, W.J. (1992b). Parasitism of wild Gouldian Finches *Erythrura gouldiae* by the air-sac mite *Sternostoma tracheacolum*. *Journal of Wildlife Diseases* **28**, 80-84

Woinarski, J., Mackey, B., Nix, H. and Traill, B. (2007b). *The nature of northern Australia: natural values, ecological processes and future prospects*. ANU e-press, Canberra.

Woinarski, J., Pavey, C., Kerrigan, R., Cowie, I., and Ward, S. (2007a). *Lost from our landscape: threatened species of the Northern Territory*. NT Government Printer, Darwin.

Woinarski, J.C.Z. (1990). Effects of fire on bird communities of tropical woodlands and open forests in northern Australia. *Australian Journal of Ecology* **15**, 1-22.

Woinarski, J.C.Z., and Tidemann, S.C. (1991). The bird fauna of a deciduous woodland in the wet-dry tropics of northern Australia. *Wildlife Research* **18**, 479-500.

Woinarski, J.C.Z., and Tidemann, S.C. (1992). Survivorship and some population parameters for the endangered Gouldian Finch *Erythrura gouldiae* and two other finch species at two sites in tropical northern Australia. *Emu* **92**, 33-38.

Woinarski, J.C.Z., Milne, D.J., and Wanganeen, G. (2001). Changes in mammal populations in relatively intact landscapes of Kakadu National Park, Northern Territory, Australia. *Austral Ecology* **26**, 360-370.

Woinarski, J.C.Z., Williams, R.J., Price, O., and Rankmore, B. (2005). Landscapes without boundaries: wildlife and their environments in northern Australia. *Wildlife Research* **32**, 377-388.

APPENDIX A - MODEL PARAMETERS

Project Parameters

To access these settings click *Project: Name* on the setup tree in the model interface.

Parameter	Description
BBN	
HabitatBBN	File name (full path) of the BBN (Netica file *.neta) for the habitat suitability BBN.
Settings	
OutputFilename	The name of the output file to be used for temporal simulation (non spatial) data output including extension (e.g. output.dat). This is the filename only and does not include the path. This file will be saved in the application directory of the GIS mdx project file.
Project Name	Name of the current project
Output raster group	Name of the layer group to be created in ArcMap containing all output rasters for the current simulation.
Output raster name	Start of the output raster (img) filenames. The date string will be added for each layer created. e.g. HS will produce HS_1_Jan_1999.img
Spatial	
Analysis Style	***No Raster*** This analysis will only output data for the single pixel at the location ***CellLocationX*** and ***CellLocationY*** specified by the user. No raster layers are created in this simulation. ***Single cell*** This analysis will only output data for the single pixel at the location ***CellLocationX*** and ***CellLocationY*** specified by the user. A single pixel raster of 1ha in size will be created. ***Spatial extent*** This full spatial analysis used the spatial extent specified in the Spatial Analyst extension of ArcGIS. All pixels within this area will be analysed and a full raster output layer(s) will be created.
Cell location X	The x coordinate of the cell to be simulated in a single cell simulation (UTM m)
Cell location Y	The y coordinate of the cell to be simulated in a single cell simulation (UTM m)
Temporal	

Parameter	Description
Breeding Fledging	Date fledging begins. This must be supplied as a full date dd/mm/yyyy but the year will be ignored.
Breeding Nesting	Date nesting begins. This must be supplied as a full date dd/mm/yyyy but the year will be ignored.
PreBreeding	Date pre-breeding begins. This allows nest selection and defending to occur before nesting. May be same date as nesting. This must be supplied as a full date dd/mm/yyyy but the year will be ignored.
Breeding Stops	Date breeding stops and nesting no longer influences finch movement. This must be supplied as a full date dd/mm/yyyy but the year will be ignored.
Output Interval	The interval to be used between habitat suitability calculations. ***Day***, ***week***, ***month*** or ***year***.
Output Step	The number of ***output interval*** (see above) steps between habitat suitability calculations. For example an output interval of week and an output step of 3 would result in habitat suitability calculations being performed every three weeks between the start date and stop date.
PauseBetweenSteps	This switch (true/false) determines whether the model pauses after the BBNs have been calculated each step. This allows the user to switch to Netica and view the current BBN settings as supplied by the model for the pixel specified in Spatial settings. Selecting ok from the popup window will move to the next step, selecting cancel will turn pausing off and complete the simulation.
Start Date	Date to start calculations. The model will spin up to this date with the available daily rainfall records to ensure that the model is at the correct rainfall settings at the start of the simulation.
Stop Date	Date to finish simulation.

Grass Species Parameters

The specific setting for each grass species included in the model cane be accessed by selecting the grass species name in the Grass Species section of the setup tree.

A new grass species can be added to the simulation by clicking the <add new grass> node.

The currently selected grass species can be removed from the simulation by clicking the delete button in the tool bar when the grass species is selected.

Parameter	Description
BBN	
BBN file	The full file path to the BBN file (Netica file, *.neta) for the currently selected grass species.
Details	
Dormancy	The month after which seed dormancy breaks and seed will germinate with suitable rainfall. (1=Jan, 12 = Dec).
Fire Recovery	Specifies the number of years required before a species will seed after fire. This is recorded in whole years up to the start of the current wet season. For example if a wet season fire occurred in November and plants took two years to recover there would be no seeding the following year, but all plants would germinate with the first rains the year after and not wait until the exact two year anniversary of the fire.
GrassType	***Annual Sorghum*** Specifies the species is an annual sorghum. Particular sections of the model relate specifically to this species. ***WA Triodia*** Specifies the species is a Triodia species in Western Australia. Particular sections of the model relate specifically to this species for certain characteristics. ***Perennial*** A perennial grass species. These species are combined in the model to determine the current perennial seed availability for any pixel. ***Annual*** An annual grass species. NOT CURRENTLY USED. ***Unknown*** An unknown grass species type. NOT CURRENTLY USED.
Distribution Type	This setting defines the method of determining the species presence or absence from a pixel using the species distribution layer. ***Cutoff*** Use a specified cut-off value (***Present cutoff***) to classify the presence of the species in a pixel from the probability of presence. ***Model*** Use the probability of the species being present in the cell (taken from the grass species model layer) to set the probability of occurrence states in the species present node of the BBN. This approach will include the variation in the likelihood of a species being present (0-1) in the model and influence grass biomass and seed production accordingly.

Parameter	**Description**
Present Cutoff	The cut-off value (double) to specify the present/absent cut-off to be used when reading the species distribution model from the GIS layer when using the ***Cutoff*** style in the *distribution type* setting. This layer will usualy present a value form 0-1 and changing the cut-off allows the sensitivity of determining whether a species is present to be changed.
Title	Title to be used when reporting on this species in output
GIS Layers	
Layer	Name of the GIS layer containing grass presence data. You can drag a layer from the ArcGIS Layer tree onto this field to fill it or supply the name of the layer. The layer must exist.

Rainfall Parameters

Parameter	**Description**
Settings	
AverageRainfall	The average annual rainfall for the simulation location (mm)
Break Dormancy	The cumulative rainfall required after the [EndDryMonth] before germination occurs. Based on the results of Lewis (2007), this should be set to 20mm. Otherwise, too much time passes before grasses germinate and the onset of seeding is deferred passed that reported in the field. If a storm of specified size (***InitailStorm***) happens before this cumulative rainfall is reached, dormancy is also broken.
End dry month	The last month of the dry after which rainfall (storms) can herald the start of the wet season. (1 Jan – 12 Dec).
Filename	The full filename of the daily rainfall file. ASCII Comma delimited in the following format YYYY,MM,DD,mm (no header row permitted). Dates with zero rainfall can be ignored or entered, but must have a 0 in the 4th column if entered.
Initial Storm	The size of an individual daily rainfall event (considered a storm) to break dormancy. Lewis (2007) data found that this is probably not the trigger and cumulative rainfall is a better estimate of germination. If the cumulative rainfall (***BreakDormancy***) is achieved before a storm of specified size, dormancy is also broken.
MonthlyFilename	A file of average monthly rainfall to track whether the current season's rainfall is above or below average. ASCII file with monthly average per line from January – December.

Spatial Layers Parameters

Parameter	Description
Details	
Layer	The name of the GIS layer to be used to define the property. Cut-offs are generally defined in the BBN. Future versions will allow user specified cut-offs. This can be filled by dragging and dropping a layer from the current ARCGIS Map or filling manually. The layer must exist.
RasterLayer	Layer raster. Read only.
Title	Layer title. Read only.

Fire Parameters

The specific setting for each fire included in the model can be accessed by selecting the fire name in the Fires section of the setup tree.

A new fire can be added to the simulation by clicking the <add new fire> node.

Parameter	Description
Details	
Date	The date of the fire.
Layer	The name of the GIS layer to be used to define the extent of the fire. This can be filled by dragging and dropping a layer from the current ARCGIS Map or filling manually. The layer must exist.
NoFireValue	The pixel value specifying a cell was not burnt by this fire. No fire mask, default 0.
TimingOfFire	Specify if the fire occurred in the dry season or wet season. At present this is user specified rather than tries and determine from the date of fire. See report for details of the fire types.
Title	Name of the fire. e.g. “lowland management burn by roads”.

Parameter settings for simulation in this report

The following table provides the parameter values used for simulations in this report. Values not affecting the results such as *Project Name* have not been included.

Parameter	**Setting**
Spatial	
Coordinate System	GDA94
Analysis Extent	(set via ArcMap Spatial Analyst, UTM) Top – 8443985.57 Bottom – 8423985.57 Left – 172963.353 Right – 192963.353
Pixel size	500 x 500 m (40x40 pixel extent)
Fire map	Full site 33% site burned (see Figure 19)
Distance to nests	Figure 11
Distance to permanent water	See Figure 10
Distance to drainage	< 200 classified run-on water receiving >200 classified run-off water shedding See Figure 12
Ruggedness index	< 4.99 considered Flat >4.99 classified Rocky/Rugged See Figure 13
Temporal	
Pre-Breeding	25 February
Nesting	10 March
Fledging	1 April
Breeding stops	3 August
Rainfall	
Average annual	995 mm
End dry season	August
Storm size to	10 mm

Parameter	Setting
break dormancy	
Cumulative rainfall to break dormancy	20 mm
Daily rainfall	Daily rainfall records recorded at Edith Falls Ranger Station.
Monthly averages	235.1,212.6,161.7,32.8,5.6,2.0,1.0,0.5,5.9,29.0,88.6,196.8

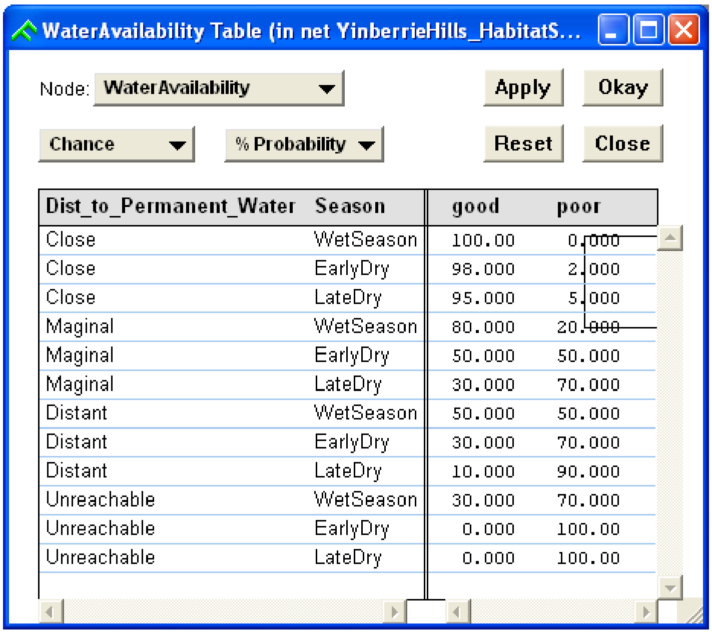
Parameter	*Sorghum intrans*	*Chrysopogon fallax*	*Alloteropsis semialata*	*Triodia bitextura*
Grass species distributions	See Figure 8			
Distribution method	Model	Model	Model	Model
Dormant until	August	August	August	August
Fire recovery (years post fire)	0	0	0	3
Type	Annual sorghum	Perennial	Perennial	Perennial
Run on seeding offset (weeks)	-2	-1	0	2

APPENDIX B - CONDITIONAL PROBABILITY TABLES AND NODE STATE CUT-OFFS

Several nodes in the Bayesian Belief Networks are temporally or spatially dynamic and therefore their findings are determined by the model from rainfall data or spatial maps at the time of calculation. Some of these nodes use continuous values (e.g. weeks since last rain) and the cut-offs to determine categorisation are provided in the Netica BBN file. Other nodes require a Conditional Probability Tables (CPT) to be supplied. This section outlines all the nodes used in the habitat suitability and grass seeding BBNs that require a CPT and the values used for this study.

Habitat suitability BBN

The relationship between distance to water and season in determining the water availability of a pixel for Gouldian finches is provided in Figure 21. This shows the decrease in water availability with increasing distance to permanent water and progressions from the wet to dry seasons.



Node: WaterAvailability

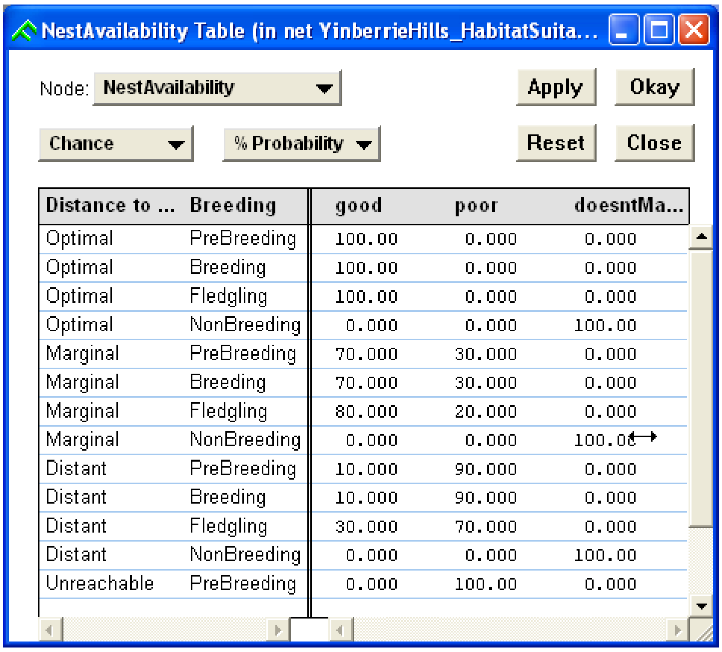
Chance

% Probability

Dist_to_Permanent_Water	Season	good	poor
Close	WetSeason	100.00	0.000
Close	EarlyDry	98.000	2.000
Close	LateDry	95.000	5.000
Maginal	WetSeason	80.000	20.000
Maginal	EarlyDry	50.000	50.000
Maginal	LateDry	30.000	70.000
Distant	WetSeason	50.000	50.000
Distant	EarlyDry	30.000	70.000
Distant	LateDry	10.000	90.000
Unreachable	WetSeason	30.000	70.000
Unreachable	EarlyDry	0.000	100.00
Unreachable	LateDry	0.000	100.00

Figure 21. The conditional probability table for the water availability node of the habitat suitability BBN given season and distance to permanent water.

The probabilities used to determine nest availability from distance to nests and breeding season are provided in Figure 22. This table explains how distance to nests is not important outside the breeding season where the ***doesn't matter*** state is set.



Node: NestAvailability

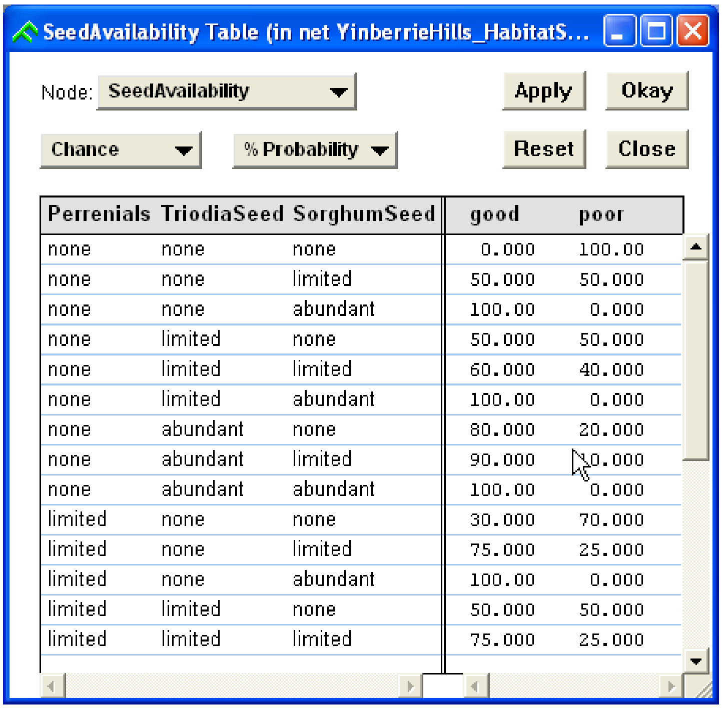
Chance

% Probability

Distance to ...	Breeding	good	poor	doesntMa...
Optimal	PreBreeding	100.00	0.000	0.000
Optimal	Breeding	100.00	0.000	0.000
Optimal	Fledgling	100.00	0.000	0.000
Optimal	NonBreeding	0.000	0.000	100.00
Marginal	PreBreeding	70.000	30.000	0.000
Marginal	Breeding	70.000	30.000	0.000
Marginal	Fledgling	80.000	20.000	0.000
Marginal	NonBreeding	0.000	0.000	100.00
Distant	PreBreeding	10.000	90.000	0.000
Distant	Breeding	10.000	90.000	0.000
Distant	Fledgling	30.000	70.000	0.000
Distant	NonBreeding	0.000	0.000	100.00
Unreachable	PreBreeding	0.000	100.00	0.000

Figure 22. The conditional probability table for the nest availability node of the habitat suitability BBN given breeding season and distance to nest sites.

The seed availability node of the habitat suitability BBN is set as a combination of the current state of each grass species simulated in the model. The process-based component of the model is used to propagate the ***perennial seed*** node by using a cumulative combination of all grass species classified as perennial. Two separate nodes exist for annual *Sorghum* and Western Australian *Triodia* as these were considered to influence seed availability to different extents than the combined perennial seeds. The relationship of these different categories to the final seed availability state is provided in Figure 23.



Node: SeedAvailability

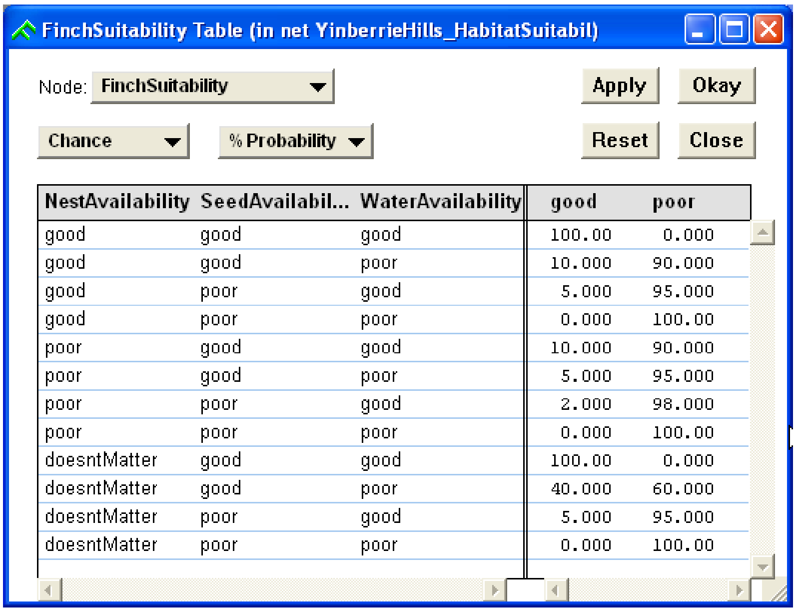
Chance

% Probability

Perrenials	TriodiaSeed	SorghumSeed	good	poor
none	none	none	0.000	100.00
none	none	limited	50.000	50.000
none	none	abundant	100.00	0.000
none	limited	none	50.000	50.000
none	limited	limited	60.000	40.000
none	limited	abundant	100.00	0.000
none	abundant	none	80.000	20.000
none	abundant	limited	90.000	10.000
none	abundant	abundant	100.00	0.000
limited	none	none	30.000	70.000
limited	none	limited	75.000	25.000
limited	none	abundant	100.00	0.000
limited	limited	none	50.000	50.000
limited	limited	limited	75.000	25.000

Figure 23. The conditional probability table for the seed availability node of the habitat suitability BBN given the seed availability of *Sorghum,* WA *Triodia* and the combined perennial grasses.

The finch suitability probability table is provided in Figure 24. This table allows the relative effects of each effect to be considered in the final estimate of habitat suitability. It was found that when any node is unsuitable, the habitat suitability should also be unsuitable for the overall layers to work effectively.



Node: FinchSuitability

Chance

% Probability

NestAvailability	SeedAvailabil...	WaterAvailability	good	poor
good	good	good	100.00	0.000
good	good	poor	10.000	90.000
good	poor	good	5.000	95.000
good	poor	poor	0.000	100.00
poor	good	good	10.000	90.000
poor	good	poor	5.000	95.000
poor	poor	good	2.000	98.000
poor	poor	poor	0.000	100.00
doesntMatter	good	good	100.00	0.000
doesntMatter	good	poor	40.000	60.000
doesntMatter	poor	good	5.000	95.000
doesntMatter	poor	poor	0.000	100.00

Figure 24. The conditional probability table for the habitat suitability node of the habitat suitability BBN given the seed availability, water availability and nest availability.

Grass Species BBNs

The difference between *Sorghum intrans* and other grass species is that *Sorghum intrans* parameterisation allows a seed bank to persist through the dry season after seeding while the plant is post-seeding and dormant. This is only possible on the rocky/rugged soils as *Sorghum intrans* seeds burrow and are lost as a food resource for finches in the flat areas with sandy/loam soils.

Grazing influences grass species to different extents. Grazing does not influence sorghum via consumption, but high levels of grazing (especially feral pigs) will reduce sorghum via trampling and disturbance. One table is used (Figure 4) to define grazing pressure from the levels of feral pigs and cattle in a pixel. Separate tables are then supplied for each species to determine the specific influence of grazing pressure on the grass biomass.

The nodes requiring values from the process-based or GIS components of the model are provided in Table 3. This table also provides the cut-off values used to classify the various node states.

Table 3. The possible node states and cut off values used in this study for the grass species BBNs.

Node	**Source**	**Value**	**State**	**Cut-offs/Probabilities**
Present	Species distribution GIS layer	double (0-1)	No	<= 0.5
			Yes	> 0.5
		The probability of Yes can be provided by the probability of the species being present from species distribution models.		
Cattle	Cattle distribution GIS layer	double (0-1)	None	Not defined for this study
			Few	
			Many	
Feral Pigs	Feral pig distribution GIS layer	double (0-1)	None	Not defined for this study
			Few	
			Many	
Grazing Pressure	BBN		None	See table.
			Low	
			High	
Wet Season Rainfall	Calculated by model		Below-Average	Calculated based on current wet season rainfall and monthly average rainfall.
			Above-Average	

Hydrology	GIS distance to water course layer	Distance (m)	Run On	0-200
			Run Off	> 200
Weeks since last rain	Calculated by model	Weeks	Wet Continues	0-2
			Rain just stopped	2-6
			Wet finished	>6
Soil water	BBN			
Landform	Ruggedness GIS layer		Flat	0-4.99
			Rugged-rocky	>=5

Rainfall and phenology

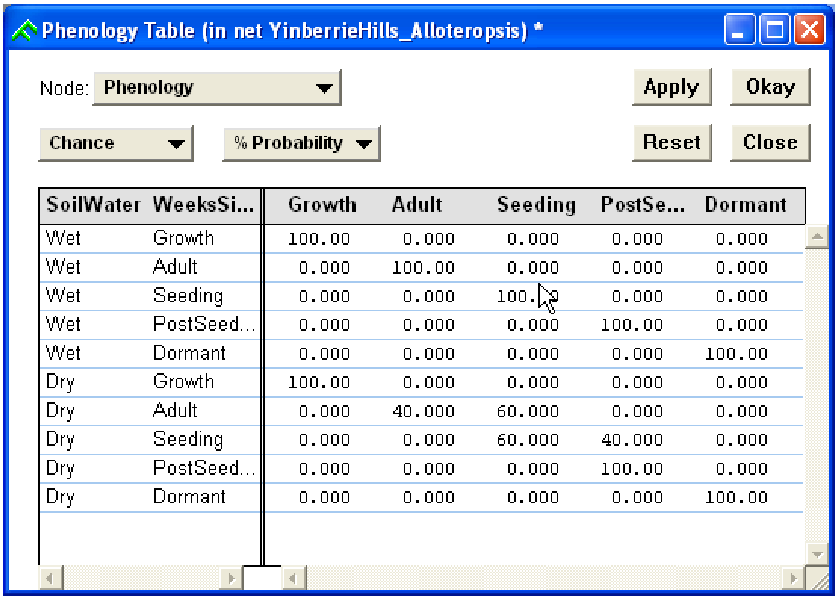
Weeks since germination rain is used as a measure of the growth and life phase of the grasses present. Table 4 shows the weeks since germination rain for the various life phases of the grasses reported in Lewis (2007) and from the values provided at the second experts workshop (ew#2). Data for Sorghum were taken from Andrew and Mott (1983).

Table 4. Weeks since germination for various life stages of the important grass species for Gouldian Finches. Brackets represent values used in the model and taken from sources other than Lewis (2007). ew#2 values were provided from expert workshop #2 (20th January 2009). *Sorghum* vales were taken from Andrew and Mott (1983).

Phase	*Sorghum intrans*	*Triodia bitextura*	*Chrysopogon falax*	*Alloteropsis semialata*	*Heteropogon sp*
Growth	(0)	(0)	(0)	(0)	(0)
Adult	(12)	(7)	(9)	(7)	(7)
Seeding	(21)	9.5	10 (7 ew#2)	8.5 (6 ew#2)	15
PostSeeding	(23)	13.5	13.5 (9 ew#2)	12.5 (8 ew#2)	23
		Feeding observed for 4 weeks	Seeds available for three weeks		Seeds avail Feb and March = 8 weeks
Dormant	(28)	(18)	(18)	(18)	(34)

The rainfall-phenology conditional probability table (CPT, Figure 25) allows the phenology (or life stage) of the grass species to be modified from that determined by time since first storms (wet-season onset and germination). It allows drying of the soil before normal seeding time to initiate some seed production (60%). It also allows seeding to be reduced (60%) in dry runoff areas to stop production at the end of the wet season.

Initially this table was also used to allow early onset seeding in run-on cells (60%), but this functionality has since been moved into the process-based component of the model to directly alter the number of days since fire for cells that are classified as run-on.



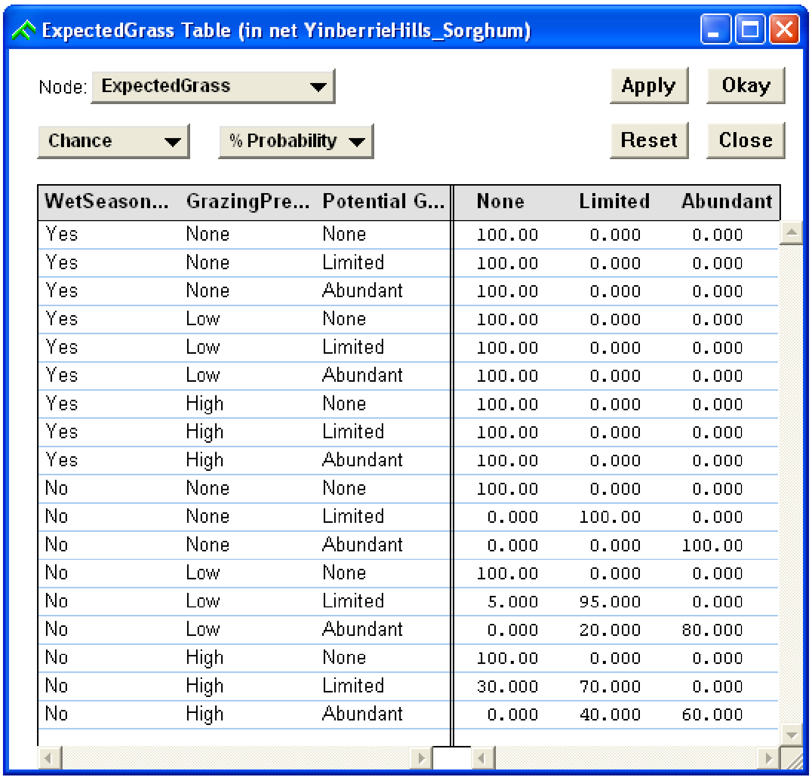
SoilWater	WeeksSi...	Growth	Adult	Seeding	PostSe...	Dormant
Wet	Growth	100.00	0.000	0.000	0.000	0.000
Wet	Adult	0.000	100.00	0.000	0.000	0.000
Wet	Seeding	0.000	0.000	100.00	0.000	0.000
Wet	PostSeed...	0.000	0.000	0.000	100.00	0.000
Wet	Dormant	0.000	0.000	0.000	0.000	100.00
Dry	Growth	100.00	0.000	0.000	0.000	0.000
Dry	Adult	0.000	40.000	60.000	0.000	0.000
Dry	Seeding	0.000	0.000	60.000	40.000	0.000
Dry	PostSeed...	0.000	0.000	0.000	100.00	0.000
Dry	Dormant	0.000	0.000	0.000	0.000	100.00

Figure 25. Conditional probability table showing the relationship between soil water and weeks since first storms used for all grass species. Probabilities are displayed as percentages.

It appears that time since germination may not be the only measure of seeding timing as late onset of rains does not necessarily result in a delayed seeding (2002-2003 seasons Lewis, 2007). It is therefore more likely a temperature, light or water trigger. If a soil water trigger, the model could currently be accounting for this as drying soil triggers seeding is the current model.

Sorghum

The probability table for ***expected grass*** for *Sorghum* shows limited affect of grazing on this species except through trampling as grazing intensity increases (Figure 26). Wet season fires remove all sorghum production. The ***GrazingPre…*** column is the grazing intensity of the cell, ***WetSeason…*** column is wet season fire and ***Potential G...*** is the potential grass production from rainfall and whether the species is present.



ExpectedGrass Table (in net YinberrieHills_Sorghum)

Node: ExpectedGrass

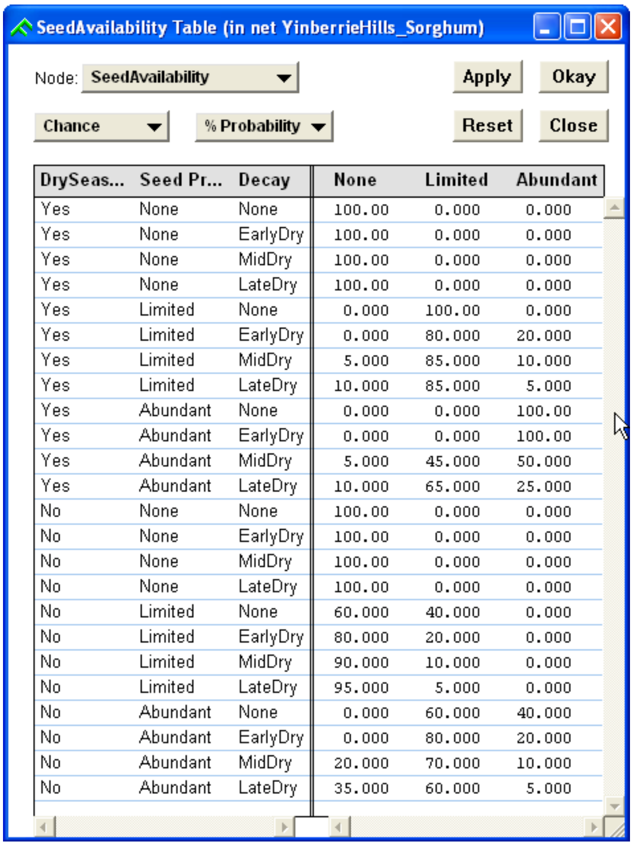
Chance

% Probability

WetSeason...	GrazingPre...	Potential G...	None	Limited	Abundant
Yes	None	None	100.00	0.000	0.000
Yes	None	Limited	100.00	0.000	0.000
Yes	None	Abundant	100.00	0.000	0.000
Yes	Low	None	100.00	0.000	0.000
Yes	Low	Limited	100.00	0.000	0.000
Yes	Low	Abundant	100.00	0.000	0.000
Yes	High	None	100.00	0.000	0.000
Yes	High	Limited	100.00	0.000	0.000
Yes	High	Abundant	100.00	0.000	0.000
No	None	None	100.00	0.000	0.000
No	None	Limited	0.000	100.00	0.000
No	None	Abundant	0.000	0.000	100.00
No	Low	None	100.00	0.000	0.000
No	Low	Limited	5.000	95.000	0.000
No	Low	Abundant	0.000	20.000	80.000
No	High	None	100.00	0.000	0.000
No	High	Limited	30.000	70.000	0.000
No	High	Abundant	0.000	40.000	60.000

Figure 26. The conditional probability table for Sorghum expected grass biomass based on potential grass biomass, wet season fire and grazing pressure in the Sorghum species grass BBN.

As Sorghum is only species with a dry season seed bank, the seed availability probability table is different for this species than other grasses (Figure 27). Dry season fire improves seed accessibility for finches while increasing loss of seed occurs through the dry season from decay and consumption etc.



SeedAvailability Table (in net YinberrieHills_Sorghum)

Node: SeedAvailability

Chance

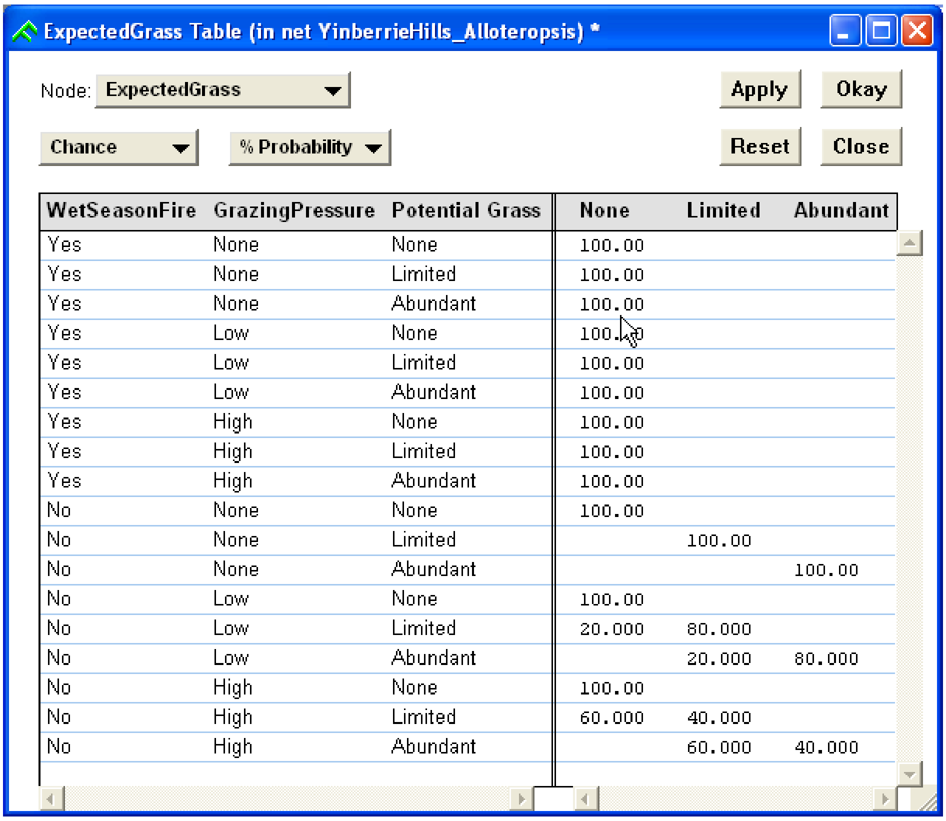
% Probability

DrySeas...	Seed Pr...	Decay	None	Limited	Abundant
Yes	None	None	100.00	0.000	0.000
Yes	None	EarlyDry	100.00	0.000	0.000
Yes	None	MidDry	100.00	0.000	0.000
Yes	None	LateDry	100.00	0.000	0.000
Yes	Limited	None	0.000	100.00	0.000
Yes	Limited	EarlyDry	0.000	80.000	20.000
Yes	Limited	MidDry	5.000	85.000	10.000
Yes	Limited	LateDry	10.000	85.000	5.000
Yes	Abundant	None	0.000	0.000	100.00
Yes	Abundant	EarlyDry	0.000	0.000	100.00
Yes	Abundant	MidDry	5.000	45.000	50.000
Yes	Abundant	LateDry	10.000	65.000	25.000
No	None	None	100.00	0.000	0.000
No	None	EarlyDry	100.00	0.000	0.000
No	None	MidDry	100.00	0.000	0.000
No	None	LateDry	100.00	0.000	0.000
No	Limited	None	60.000	40.000	0.000
No	Limited	EarlyDry	80.000	20.000	0.000
No	Limited	MidDry	90.000	10.000	0.000
No	Limited	LateDry	95.000	5.000	0.000
No	Abundant	None	0.000	60.000	40.000
No	Abundant	EarlyDry	0.000	80.000	20.000
No	Abundant	MidDry	20.000	70.000	10.000
No	Abundant	LateDry	35.000	60.000	5.000

Figure 27. The conditional probability table for Sorghum seed availability based on dry season fire, seed production and decay in the Sorghum species grass BBN.

Other species

As the non Sorghum grass species do not have the specific characteristics of *Sorghum intrans* (i.e. persistent seed bank), they have the same probability tables for many nodes. It is the cut offs values for phenological phases based on weeks since first storms that differentiates the other species. Another node that may vary between grass species is the effect of grazing as determined through the ***Expected Grass*** probability table. Figure 28 shows this probability table for *Alloteropsis semialata* where, unlike the Sorghum equivalent (Figure 26), the probability of maintaining grass biomass is reduced as grazing pressure increases.



ExpectedGrass Table (in net YinberrieHills_Alloteropsis) *

Node: ExpectedGrass

Chance

% Probability

WetSeasonFire	GrazingPressure	Potential Grass	None	Limited	Abundant
Yes	None	None	100.00		
Yes	None	Limited	100.00		
Yes	None	Abundant	100.00		
Yes	Low	None	100.00		
Yes	Low	Limited	100.00		
Yes	Low	Abundant	100.00		
Yes	High	None	100.00		
Yes	High	Limited	100.00		
Yes	High	Abundant	100.00		
No	None	None	100.00		
No	None	Limited		100.00	
No	None	Abundant			100.00
No	Low	None	100.00		
No	Low	Limited	20.000	80.000	
No	Low	Abundant		20.000	80.000
No	High	None	100.00		
No	High	Limited	60.000	40.000	
No	High	Abundant		60.000	40.000

Figure 28. The conditional probability table for the expected grass biomass of *Alloteropsis semialata* given wet season fire, potential biomass and grazing pressure.

APPENDIX C - USER MANUAL

System Requirements

The Gouldian Finch Management System requires a Windows based machine with licensed versions of ARCGIS (ESRI) Spatial Analyst (ArcGIS add-on) and Netica (Norsys) already installed. You will also require your computer to have the .Net 3.0 framework installed. This is included with Windows® Vista and the latest Windows® XP updates and service packs so should be installed if your machine is patched and up to date.

Installation

1. Run the setup file provided.
2. Open ARCGIS.
3. Open the Map with data layers you wish to analyse (MDX file).
4. Insert the Gouldian Finch Management System toolbar button. This is achieved through the tools\customise menu options. The button is located in the COM tab under the CSIRO folder.
5. Open the dockable user interface with the toolbar button

Data Requirements

Spatial data

The analysis resolution used by the model is determined by the pixel size of the spatial data supplied. The following GIS raster layers must be supplied and they must also all be aligned such that they have the same top-left and bottom-right coordinates and same pixel size.

Layer	Unit of measure
Distance to drainage. The distance to drainage lines in metres from any pixel. This is used in the grass germination and seeding timing component	metres
Distance to permanent water. The distance to permanent water (i.e. dry season water) from any pixel. This is used to determine distance to water for the birds	metres
Land form. A landform layer is required to classify flat (sandy/loam) from rugged (rocky/sandy) pixels. In this study a Ruggedness index (the difference between adjacent pixels) was used with a	N/A

Layer	Unit of measure
specified cut off. Additional layers defining these types could be provided with pixel values of x and y defining flat and rugged/rocky respectively.	
Distance to nests. The distance to nest sites to any pixel. This is used to determine distance to nesting for the birds	metres
Grass species presence. A layer provided for each grass species in the model providing the probability of the grass species being present in the pixel. This can be determined from distribution maps or species presence models. 0=absent, 1=present.	Probability of the grass species being present in any cell (0-1).

Temporal Data

Historic daily rainfall is supplied to the model as an ASCII comma delimited with no header row and columns for year, month, day, and rainfall (mm). This file may contain entries for zero (0) rainfall or these may be omitted.

Average monthly rainfall is supplied to the model as an ASCII comma delimited with no header row and columns for month and average rainfall (mm). A record must be present for every month (January – December) and zero rainfall where the average is zero.

Setup

All model parameters are provided in the Setup tab of the user interface. The various sections are accessed by selecting the desired section of the setup tree. For example general settings are available by clicking the project name and specific grass species settings by clicking the grass species. These will be defined in greater detail below.

The current settings can be saved to a project file at any time using the *Save Project* button on the toolbar. Likewise, a previously save project can be opened at any time.

NOTE: The current settings will automatically be saved upon exiting ArcGIS Gouldian Finch Management System and prior to performing any simulation.

Model

See Appendix A - of the project report for a full description of the parameters available in the model.

Output

Spatial data

A raster output layer of habitat suitability will be created for each time step in a simulation and stored within the HabitatSuitability group in the ArcMap layers tree. The colour display and transparency of these layers are automatically set.

Temporal data

The value of any node in any BBN used in the simulation can be sent to the output file specified in the Model Settings section. A record will be created for each time step based on the pixel specified.

The Output tab of the user interface is used to access output settings. Explore the tree of all BBNs, Nodes and States and simply set the check box beside a node state to include the probability of that state in the output.

Logs

A log of simulation information is provided in the Log tab of the model interface. This area is used to provide all warnings and errors in model setup and provide the status of current simulations.

The check settings button on the toolbar can be used at any time to check the current model setup before running the model.

Contact Us

Phone: 1300 363 400
+61 3 9545 2176
Email: enquiries@csiro.au
Web: www.csiro.au

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