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Representing Indigenous wetland ecological knowledge in a Bayesian Belief Network

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Abstract: It is widely appreciated that Indigenous Australians hold a wealth of ecological knowledge that could be beneficially applied to contemporary land management. However, this has rarely happened, and unfortunately a large amount of Indigenous knowledge is being lost as elders pass away. The Bayesian Belief Network (BBN) approach is ideal for recording traditional ecological knowledge and applying it to land management as it can use qualitative information in the form of expert opinion using local terminology. Once a model is developed, the BBN approach also provides an intuitive means of exploring system dynamics, therefore offering an effective educational tool for Indigenous and non-Indigenous people alike. The collaborative process of model development also fosters new relationships and a better understanding of the ecosystem by all parties. This project was designed to examine the how Indigenous land managers recognise and manage for healthy wetlands. This was achieved by working with a family of Aboriginal land managers, a number of whom are traditional owners in Kakadu National Park. A BBN was developed to formalise the integration of western and indigenous knowledge systems, and to develop a visually appealing, interactive, educational experience for a diverse audience, from Aboriginal land managers to tourists and park management. A web-based, graphical presentation was then developed to clearly present BBNs and display additional underlying knowledge. This paper presents the process and unique challenges in developing the BBN with Indigenous Australians who have not been previously exposed to western modelling approaches.

Keywords: *Kakdau National Park, Aboriginal land management, wetland health, fire management*

1. INTRODUCTION

Wetlands have long been important places for food collection by the Aboriginal people of Kakadu National Park, Northern Territory. Not surprisingly, food (or bush tucker) accessibility is key to the Indigenous understanding of wetland health. Indigenous Australians hold a wealth of ecological knowledge and land management understanding about wetlands. It is now widely appreciated how this understanding can be beneficially applied to contemporary land management, however this has rarely occurred. Unfortunately, a lot of valuable knowledge is lost as elders pass away before it can be passed on to the next generations.

This project aimed to use the features of Bayesian modelling, in particular Bayesian Belief Networks (BBN), to represent Aboriginal knowledge about healthy wetlands and disseminate this understanding to a wider audience. The desirable features of this approach included the ability to use expert understanding to develop the model using local terminology and present the model in a visual way to explain the interacting processes incorporated. This paper will describe the steps involved in developing this model with Aboriginal land managers and the web-based visualisation of a BBN developed.

2. DEVELOPMENT OF THE BAYESIAN BELIEF NETWORK

Other studies (Baran and Jantunen, 2004) have considered the process of consulting stakeholders to develop BBNs, but few if any have involved Aboriginal land managers as the group interested in developing the model. Developing BBNs for different stakeholder groups involves making the process clear and transparent with a sense of ownership maintained by the participants. This is especially important when working with Indigenous communities. Indigenous commentators have criticized the one-sided approach where conventional western science methodologies do not leave participants feeling a sense of ownership of the process and final products, often limiting applicability of the results and inhibiting future collaborative research (Henry et al, 2002, Dodson, 2000).

The aims of this project were to i) assist Aboriginal land managers to develop a model that adequately represents the traditional understanding of how healthy wetland systems provide bush tucker, and ii) ensure that ownership of intellectual property was retained by the traditional owners during the entire process. This meant that sufficient time was needed to develop an understanding of the logic behind the model, the model's role and potential applications. These steps built on previous interactions with Indigenous researchers and ensured that the final product was clearly a collaborative outcome with multiple benefits and uses.

The development of the BBN involved five one-day meetings undertaken in Kakadu National Park from June 2007 to May 2008. The participants included a model development coordinator, communication support officer and two Aboriginal land managers whose knowledge and understanding of wetland fire management has been passed down from Kakadu Traditional Owners. The process involved explaining the concept of models, recording traditional wetland burning understanding, developing the BBN, propagation of model probabilities and final model validation and modification. The approach undertaken aimed to lead all project participants through a progression of steps to develop the final model using plain English terminology.

2.1. Understanding models

The complexity of natural and socio-economic systems necessitates that any modelling approximation of these systems, while a simplification, will itself be somewhat complex. The wide range of modelling approaches available and their common use of mathematical equations have restricted their users to experts rather than providing a simple tool of great value to a wide range of users. It was important that all team members including project support staff and Aboriginal land managers were comfortable with the concepts used for developing the model in this project. For this reason, the first phase of this project involved discussions about models commonly used in society (e.g. weather forecasts, computer games etc) to ensure all participants were comfortable with the concept of modelling and the task we were attempting to perform.

2.2. Elicitation of model structure

The task of eliciting and representing Indigenous ecological wetland knowledge and wetland burning knowledge was performed over two one day meetings. The primary factors important to wetland health were first defined followed by discussion about additional influencing factors. As this was a small group with non-conflicting interests and understanding, a free dialog was undertaken and all details recorded. It was important that concepts important to local perceptions and understanding were included and western pre-conceptions were avoided in this process. To direct discussions and keep focused and specific for the model creation, broad areas of interest (e.g. ducks, red lilies and magpie geese) were considered separately as it was apparent that the feedbacks and links between all parts of the wetland system can easily become confusing or lead the conversation into other areas of great interest. For each factor that would represent a node in the BBN we discussed the ecological understanding and its importance to customary management of resources.

During the second meeting an influence diagram was developed to describe the traditional understanding of the processes and interactions between parts of the wetland system. This introduced participants to the relational dependencies between components and how changing one factor can lead to changes in other components that may not be immediately obvious.

2.3. Elicitation of model parameters

This model is based on the local ecological knowledge of small number of people and therefore reflects local and specific experiences. This is still a valuable source of information and avoids the information overload that may occur when consulting with a large group. The applicability of the final model can be improved in the future with input from additional Aboriginal land managers living with this system and other wetlands. Parameterisation of the model with beliefs involved two steps; determining meaningful categories for each factor and providing probabilities or likelihoods.

The model adopts local terminology to make it more accessible. One such example is the measure of abundance of plants and animals. Terms such as “big mobs”, “little bit” and “none” are used by the Aboriginal land managers and traditional owners and while they have different quantitative value depending upon the animal or plant in question they are suitable measure of abundance for the belief network and were incorporated. For example, “big mobs” of Magpie Geese represent tens of thousands of individuals in a flock while goannas are only seen individually and “big mobs” would represent a frequency of sightings. All participants were comfortable using categorically defined measures of each variable and so categorical (qualitative) measure were used throughout the BBN. One difficult node to categorise was “season” reflecting a very different understanding of time of year between western and Indigenous cultures. This is also driven by the fact that distinct seasons are difficult to define and especially link to the calendar where the timing of weather patterns differs between years.

The concept of filling the belief network with probabilities was fairly straightforward. The idea of chance and probability were readily incorporated into the model and allowed for the inclusion of rare events. Project participants realised that this approach allowed for a level of uncertainty and variability to be incorporated. When the network was built, a number of combinations with zero and 100 percent chance were converted to very small probabilities (0.0001) and almost 100 percent (99.9999) to remove the problem of inconsistent findings arising in the final model. This excluded the possibility of unrealistic combinations of factors in the model causing spurious results (and application error messages) when used by a broad audience who may not understand the consequences of the values selected.

3. RESULTS

The BBN developed is primarily a representation of system dependencies with each node influenced by a number of parent nodes, leading to the final measure of wetland health via an indication of bush tucker availability. We also used the ability of BBNs to determine the posterior likelihood of a principle node given the probability of child nodes. The BBN shows that “Season” determines “clouds”, “humidity” and “smoke”, but we can also enter these attributes to determine the likely season. This is a more intuitive way for the user to determine the current season by using visual cues and easily parameterised.

The resulting belief network (Figure 1) reveals the factors considered important by the traditional owners that may not have been included in a western science-based depiction of wetland state. For example, the presence of people in wetlands is very important, with whole concept of wetland health revolving around a system capable of providing important food resources (“bush tucker”). This accords with ethnographic studies of indigenous cosmologies that place humans in relationship with the ecological or natural world and not separate to it (e.g. Rose, 2005). The network also includes contemporary issues such as weed management and introduced feral animals such as cane toads, which have a large impact on the cultural values of the wetland.

The number of lines connecting nodes from “water level”, “season” and “choked wetland” highlights the importance of these nodes in representing wetland function. The system is dependent upon the “water level” that changes with “season”. This water level determines the life stage of plants and their availability to water birds. Water level also determines the ability of people to find turtles and file snakes as bush food. All these factors, and therefore wetland health, are strongly influenced by whether the wetland is choked by weeds such as *Mimosa pigra* and *Salvinia molesta* or native *Hymenachne acutigluma* (Mudja). Good fire management by Bininj (the traditional owners) in collaboration with park rangers and weed management by park rangers helps keep the wetland open. The open wetland provides habitat for a range of aquatic plants and the water birds that rely on them, resulting in abundant bush foods and a characteristic of good "wetland health". This understanding is similar to that presented by Rose (2005) showing how Indigenous people can "read the country" and use indicators to know when to harvest and hunt.

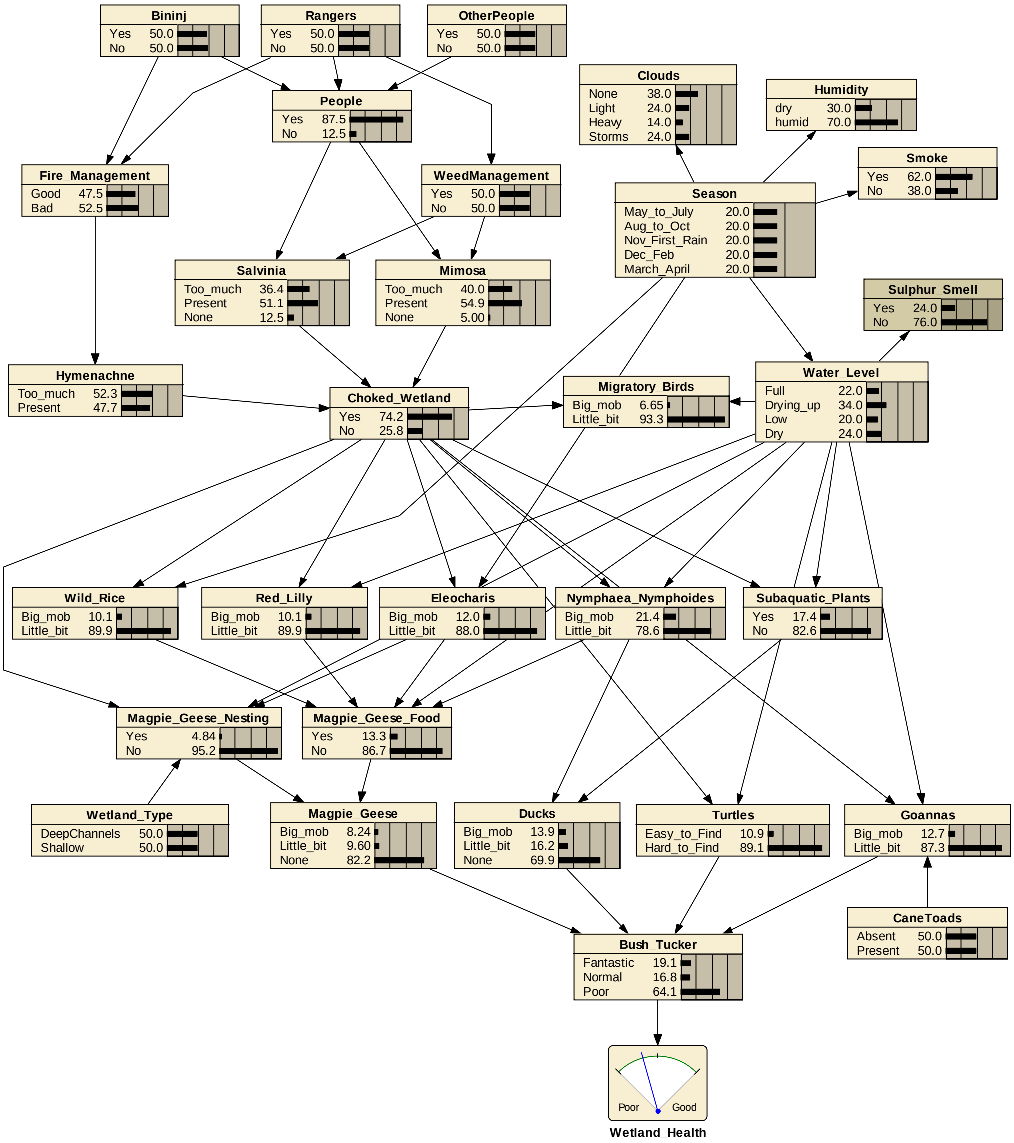

Figure 1. The Bayesian Belief Network representing Indigenous ecological knowledge about wetland health in Yellow Water, Kakadu National Park, Northern Territory, Australia.

Developing this BBN revealed the level of detailed ecological knowledge held by the traditional owners and how the final model created is only a very simple approximation of their total understanding. From the detailed discussions, the aboriginal land managers realised that there is considerable additional understanding behind the parameterisation of each connecting line between nodes. This detail, simplified in the probability tables, meant that the intellectual property around natural resource management (NRM) and wetland burning of the traditional owners is maintained and is not freely available in the model.

4. PROVIDING A USER FRIENDLY VISUALISATION OF THE BBN

One of the characteristics of the BBN approach is that the network developed provides a simplified representation of a system with lines joining nodes showing where relationships exist, much like a conventional flow diagram and model representation. This allows the user to visualise a simplification of the complex system being represented. The ability to use Bayesian Software (e.g. Netica, Norsys, 2007) to instantly analyse a full range of scenarios "on the fly" is also an advantage in model development and information dissemination. While these are clear benefits of the BBN approach, complex networks with simplified nodes can be overwhelming to a number of users not familiar with the BBNs and flow diagrams. This reduces the impact of the network's ability to clearly present the system and provide an interactive learning experience without an expert to guide the user and explain responses.

This project attempted to overcome this shortfall by replacing the standard network (Figure 1) with a more graphical representation where nodes are represented by images indicating the current state of each node (Figure 2, Figure 3). When the state of a node changes the user witnesses the effect of the change by a change in the images displayed, information supplied and sounds generated.

The visualisation component was developed as a web-based application allowing a wide audience to access the model information across a range of platforms. This involved a server-side application to manage the databases and BBN and the user interface accessed through standard web browsers. The application was developed with C# asp.NET (Visual Studio 2005, Microsoft, 2005) and uses the Netica (Norsys, 2007) file format for BBN, which is one of the most widely used applications.

The network visualiser can be configured with any number of nodes presented on a page. Thus, a single web page could represent the entire belief network or a sub section of the network relating to a particular category. As the server application can track the current state of the network for a given user, any changes made on a page will affect the findings on other pages. This allows the user to explore the various sub sections of the model individually for ease of understanding.

Those familiar with BBNs will recognise the general layout of each node represented on the web page (Figure 2). The node name presented either as the actual node name or a custom description appears above each image. Below the image is the current state, a drop down list box allowing the user to set a state, and a confidence bar. The confidence bar was added to provide an indication of the strength of the current value displayed. This bar provides the actual value as a pop-up when the user hovers the mouse over it. As the BBN is a probabilistic model there is a likelihood that any state is currently possible (unless set by the user). The visual display shows the state with the greatest likelihood and presents this likelihood in the graphical confidence bar.

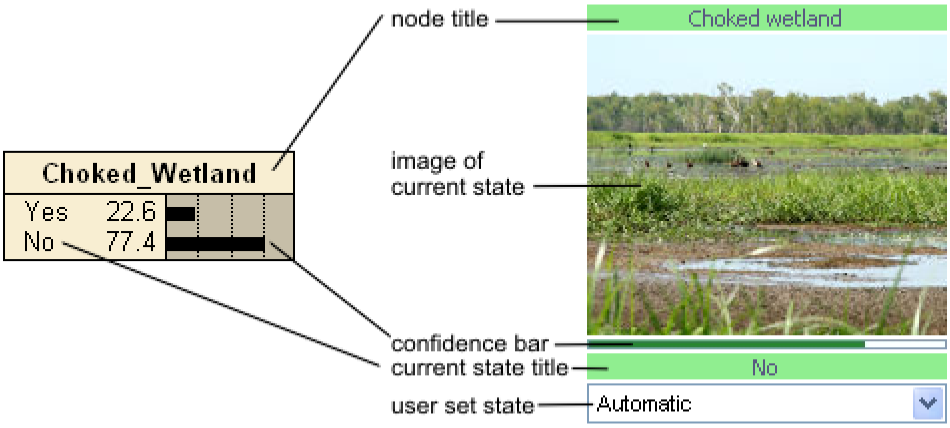

Figure 2. A Netica BBN node (left) and the visualisation of the same node for display on the web page (right) with common attributes shown.

An Aboriginal manager's understanding of wetlands includes factors such as sights, sounds and smells which have also been incorporated into the visualisation of the model. The graphical approach is able to show how wetlands look and how the colour and appearance of the wetland changes with the season. Smell has been added in the understanding with the model indicating when a sulphur smell is experienced in wetlands. Sound is also incorporated with different states of the model able to play sound files to enhance the experience. Sound grabs of Aboriginal land managers explaining the model can also be used. This is likely to be attractive to children and others wanting to hear directly from traditional owners (e.g. tourists). This provides a more personal interaction between a model and the audience and the product becomes an educational tool rather than a mathematical, predictive model.

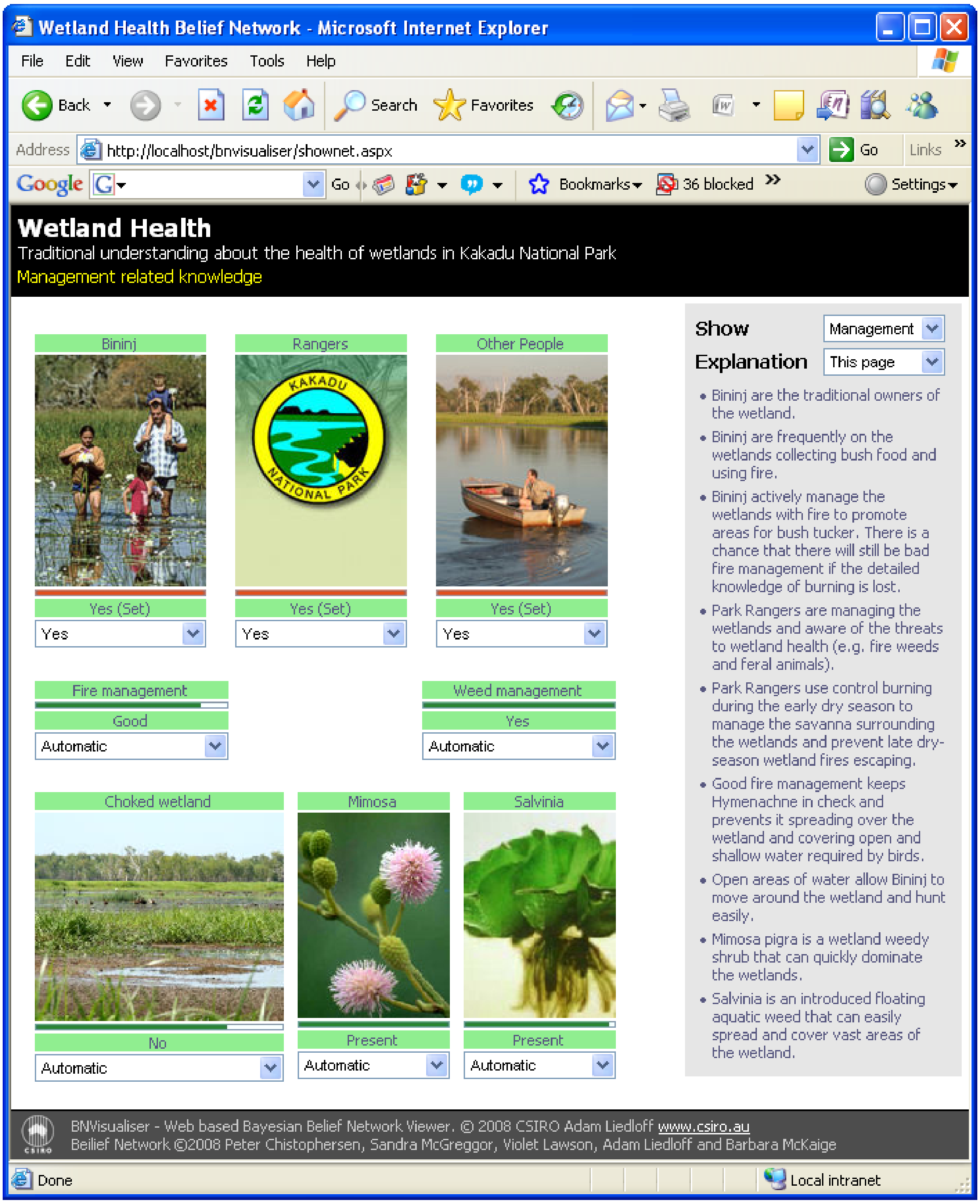

Figure 3. An example of the web-based visualisation showing the Aboriginal land management understanding of the Bayesian Belief Network developed for this project.

While the graphical visualisation allows a user to actively explore the traditional knowledge BBN, it did not provide the expert understanding to clearly explain the traditional ecological knowledge behind the model. To provide this knowledge, the model was linked to an expert commentary in the form of descriptive text snippets and sound grab files. By providing a full written dialogue of the traditional ecological knowledge behind the model a full description can be provided for each page allowing the user to understand the outcomes of the changes made to the model.

The knowledge database allows additional information to be recorded about every node, node state and interaction between a node and all influencing parent node states. This level of information effectively provides a full narrative of the state of the model as either text or sound files. The knowledge available for any state of the model is provided on the web page and the level of detail supplied can be altered by the user. This allows a user to better explore the model and gain a detailed understanding of the traditional knowledge behind the model in words and language used by the developers of the model. This knowledge database can also be provided in any language, allowing the model to be used by Aboriginal land managers who may not have English as their first language. While this knowledge provides a more detailed representation of the BBN than the network diagram alone, it does not reveal the intellectual property held in the parameterisation of the BBN. This narrative effectively provides the style of dialog one would have with an interested party and makes the experience of viewing the visual BBN more personal and easier to interpret.

5. DISCUSSION AND CONCLUSIONS

Traditional ecological knowledge and western scientific ecological knowledge share much in common and yet the two disciplines rarely combine to produce a collaborative product. This project has developed a collaborative approach allowing traditional owners in Kakadu National Park to develop a model of their wetland health understanding. Bringing Aboriginal land managers and scientists together to develop models is an important first step in producing joint outcomes and developing methodologies.

The process of developing the BBN required fostering of personal relationships, open and free discussion about wetlands, clear dialogue regarding models, explanation of flow diagrams, methodology and probabilities, and recording traditional terminology for use in the final graphical product.

The act of combining western science with local ecological knowledge in a collaborative manner is a positive achievement that will lead to further collaborative opportunities. This project has also raised some additional research questions. Further research needs to consider how the final BBN can be validated with field-based data. This is a significant area of future research. One approach towards solving this problem would be to develop two parallel models, one by Indigenous land managers and one by western scientists and have each group appraise the other group’s model. This would highlight the areas considered most important by each group and foster discussion about the relative differences in understanding. This approach would be applicable to a wide range of natural resource management issues in Australia.

During this project both scientific researchers and the traditional owners developed a new understanding of the other’s view of wetlands and believe the final product will have positive benefit and application in education and natural resource management.

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