Modelling waterbird responses to ecological conditions in the Coorong, Lower Lakes, and Murray Mouth Ramsar site

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June 2013

DEWNR Technical Report yyyy/nn

This publication may be cited as:
O'Connor, J., Rogers, D., Pisanu, P. (2013), Modelling waterbird responses to ecological conditions in the Coorong, Lower Lakes, and Murray Mouth Ramsar site. South Australian Department for Environment, Water and Natural Resources, Adelaide

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ISBN xxxxxxxxxxxx

Acknowledgements

This report represents a collaborative effort between SRC staff, CLLMM project members, other departmental staff, and external experts. Jason Higham, Rebecca Quin, Liz Barnett, and Amy George (CLLMM) supported the development and management of the project as well as providing access to datasets. Brad Page helped to initiate this project and was involved in project development. We thank the following people for providing expert advice and/or sharing datasets: David Paton (Adelaide Unievrsity), Clare Manning, Paul Wainwright, Justine Keuning (DEWNR), David and Margaret Dadd (Coorong Nature Tours), and Qifeng Yi (SARDI). Ann Nicholson and Owen Woodberry (Bayesian Intelligence) provided feedback on draft BBNs.

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Introduction

Background

Management of waterbird populations relies on knowledge of the interactions between waterbird species and their biological and physical environment. While the direct relationship between birds and their environment varies among species, in the Coorong, Lower Lakes and Murray Mouth (CLLMM) Ramsar site in South Australia, waterbird abundance and distribution is ultimately affected by water flows from the River Murray and associated ecological conditions within wetland habitats (Paton et al. 2009; Paton 2010; Keuning 2011; 2011).

Between the early 2000s-2009, prolonged drought and upstream diversion of River Murray water resulted in a cascade of adverse ecological changes in the CLLMM. Water levels in the Lower Lakes fell below sea level, exposing harmful acid-sulfate soils, and salinity in the Coorong South Lagoon increased to >200ppt (modelled natural salinity is 80ppt) (Fitzpatrick et al. 2008; Brookes et al. 2009; Webster 2010; Kingsford et al. 2011). These unprecedented conditions had a negative impact on the abundance and distribution of waterbirds as well as the fish, macroinvertebrate and plant species that make up much of their diet (CLLAMMecology Research Cluster 2008; Rogers and Paton 2008; Rogers and Paton 2009; Rolston and Dittmann 2009; Paton 2010). The abundance of key waterbird species such as the resident Fairy Tern (*Sterna nereis*), and international migrants such as the Common Greenshank (*Tringa nebularia*), decreased by 80% and 82% respectively in the Coorong South Lagoon during this time (compared to data from 1985) (Rogers and Paton 2009). As well as highlighting the limitations of current management regimes for the CLLMM site and broader Murray-Darling Basin, such changes included:

1. our incomplete understanding of how and why waterbird species respond to changing ecological conditions, and
2. our inability to forecast and effectively manage these responses.

In order to minimise the impacts of similar occurrences in the future, this project aims to increase our knowledge of the interactions between waterbirds and CLLMM habitats, and our ability to forecast and manage the consequences of ecological change for waterbirds.

Habitat modelling is increasingly used as a tool to inform the conservation and management of birds and other fauna (Poirazidis et al. 2003; Seoane et al. 2006; Liedloff et al. 2009; O'Leary et al. 2009; Vilizzi et al. 2012). A number of studies have modelled the relationships between ecological components in the CLLMM – often at the abiotic or ecosystem level (Lester and Fairweather 2009; Lester et al. 2009; Souter and Stead 2010; Webster 2010; Kingsford et al. 2011; Souter and Lethbridge 2011), however, few of these models include specific information on waterbird responses, and those that do describe interactions at the functional group level (Lester and Fairweather 2009; Souter and Stead 2010). Numerous studies highlight significant interspecific variation in the response of CLLMM waterbirds to ecological change at the site (Paton et al. 2009; Paton 2010; Paton et al. 2011; Thiessen 2011), and so these functional group responses are limited in their ability to forecast species-specific responses. There is therefore a need for species-specific waterbird models so that managers can identify and forecast critical habitat changes that will impact on waterbird species (also discussed in Paton et al. 2011; O’Connor et al. 2012)

The collection of data to inform statistical models is typically expensive and time-consuming, and, consequently, this reduces the budget for management (Field et al. 2004; Murray et al. 2009). Where there is insufficient monitoring data to populate models, expert knowledge can be an alternative source of information (Murray et al. 2009; Korb and Nicholson 2010), and this type of knowledge can be effectively incorporated into models based on Bayesian probability methods, such as Bayesian Belief Networks (O'Hagan et al. 2006; McCarthy 2007; Korb and Nicholson 2010). Bayesian Belief Networks are graphical models that are particularly useful for modelling cause and effect relationships between variables using available quantitative or qualitative (i.e. expert knowledge) data (Korb and Nicholson 2010). Information from experts can be translated into ‘prior’ probability distributions to inform model parameters (O'Hagan et al. 2006; McCarthy 2007; O'Leary et al. 2009). This approach has already been assessed (Lester and Fairweather 2008) and applied within the context of forecasting broader ecological outcomes in the CLLMM (Souter and Lethbridge 2011). Bayesian Belief Networks also provide a quantitative framework for the implementation of adaptive management, as they are iterative in nature and encourage model improvement through the collection and integration of new information as it becomes available.

The development of quantitative models will also contribute to the development of ‘Limits of Acceptable Change’ for CLLMM waterbirds. The Ecological Character Description (ECD) for the CLLMM is currently baing updated and will provide Limits of Acceptable Change (LAC) for critical components of the site. (Butcher 2011; O’Connor et al. 2012). These limits will contribute to the understanding of the Ecological Character of the site, and the environmental drivers that maintain waterbird habitat in the CLLMM.

Aims

This project develops an approach to guide management of waterbird species in the CLLMM, through the construction of conceptual and Bayesian models of avian habitat-use.

The key aims of the project are to:

1. Develop conceptual models that describe the response of avian habitat to environmental change, for ten bird species within the CLLMM.
2. Develop ecological response models (using Bayesian Belief Networks) for all ten waterbird species
3. Test and evaluate models in order to assess predictions and real outcomes.

Methods

Bayesian Methods and Adaptive Management

The application of Bayesian logic and methods is a relatively new innovation in the discipline of ecology, which has a long tradition of application of frequentist statistics for testing scientific hypotheses (McCarthy 2007). Conventional approaches to data analysis in ecology estimate the likelihood of observing data (and more extreme data in the case of null hypothesis testing). They are referred to as frequentist methods because they are based on the expected frequency that such data would be observed if the same procedure of data collection and analysis was implemented many times (McCarthy 2007). There are a number of assumptions linked to traditional hypothesis testing, such as experiments are repeatable and independent, and treatment effects are linear. In reality, these cases are difficult to meet in highly variable, complex ecological systems, and where management of these systems is complicated by many uncertainties (Prato 2005).

Bayesian methods calculate the probability of a hypothesis being true given the observed data. Relevant prior information (or knowledge) is incorporated into Bayesian analyses by specifying the appropriate prior probability for the parameters of interest. The posterior probability is the updated belief based on the data and the relative weight placed on the prior probability compared to the new data and the magnitude of difference between the two pieces of information (McCarthy 2007):

$$\text{prior} + \text{data} \xrightarrow{\text{model}} \text{posterior}$$

Frequentist and Bayesian methods differ in how they treat the notion of probability. Bayesian methods use probabilities to assign degrees of belief to hypotheses or parameter values. In contrast, frequentist methods (null hypothesis testing and information theoretic methods) are confined to stating the frequency with which data would be collected given hypothetical replicate sampling and specified hypotheses being true (McCarthy 2007).

Sampling and measurement errors and incomplete knowledge about both ecosystems and the best options for managing them mean there is a high level of uncertainty in conservation decision making. Adaptive management attempts to treat management as a hypothesis, with alternative approaches to management being designed to test this hypothesis. Adaptive management aims to reduce (but not necessarily eliminate) uncertainty about predictions of a system's response to management and be explicit about this (Walker and Salt 2012). Bayesian methods appear to be well suited to applying an adaptive management approach to ecology because they are explicit about uncertainty (Prato 2005). In practice, Bayesian statistics can be used to test competing hypotheses about managing a species or ecosystem (Prato 2005) by assigning degrees of belief to parameter values, models or hypotheses (McCarthy 2007). Bayesian methods have other practical advantages, such as being relatively straightforward to explain because they refer to factors of direct biological relevance, they are robust to different sorts of data, and are easy to update with new information (Wade 2000).

Application of Conceptual and Structured Models

Adaptive management structures management into a number of stages in a cyclic way. It includes specification of goals and objectives, modelling of existing knowledge and alternative management options, implementation of management and, ultimately, monitoring and evaluation of outcomes to create inferences about iteratively change management objectives as part of a new cycle (Sabine et al. 2004).

Conceptual models provide a visual representation of the interactions between components of a system (Margoluis et al. 2009). Models underpin adaptive management by representing beliefs about ecological system properties and dynamics, and about how the system is likely to respond to interventions (Lindenmayer and Likens 2009; Conroy and Peterson 2013). Models should describe three things – what is known, what is unknown and what is partially known (Rumpff et al. 2010). Models can also be particularly useful for identifying ecological components that need (or do not need) to be measured (Margoluis et al. 2009)

Bayesian networks or “Bayes Nets’ are a tool to develop and structure process models. They provide a method that is easily interpreted and intuitive for users, can be parameterised using a combination of data and expert knowledge, and are able to explicitly incorporate uncertainly. They are graphical models of the relationships, or causal links, between a series of predictor and response variables (Korb and Nicholson 2010; Rumpff et al. 2010).

In this study, conceptual models were developed for the following 10 waterbird species that have been assigned to one of five functional groups:

1. **Piscivores:** Fairy Tern & Greenshank
2. **Shorebirds**: Sharp-tailed Sandpiper & Red-necked Avocet
3. **Wading birds:** Great Egret & Royal Spoonbill
4. **Herbivores:** Black Swan (saline and freshwater) & Chestnut Teal
5. **Reed-dependent birds:** Purple Swamphen & Australian Spotted Crake

While these species are of interest or concern to managers, they were also chosen to represent the range of responses that might be expected from other species within the same functional group. However, this assumption needs to be tested through the development and testing of models for additional species within these functional groups.

To construct the conceptual models, a review of the habitat preferences for the chosen species was undertaken using a combination of a literature review and consultation process to capture expert knowledge. These initial conceptual models inform the development of Bayesian models by identifying the components of the CLLMM ecosystem and direction of relationships within the system that influence bird responses.

In this project, a conceptual model template was developed in order to encourage consistency in structure and content between species-specific models (Figure 1). This template assisted the model development process by identifying conceptual model categories (baseline ecological factors, drivers and limiting factors) and components that formed the basis of species-specific models. Some components of this template, e.g. ‘Hydrology’, are broad classifications that encompass a number of more specific ecological components in species-specific models. In addition, some of the template components, e.g. ‘Fledging Success’ were excluded from particular species-specific models if they were thought not to be relevant for interpreting ecological response.

In this project, conceptual models are shown as box and arrow diagrams. Mutually exclusive components are shown in boxes, and interactions among components are shown with arrows. The Limiting Factor (a particular component of the species life history), is represented by a yellow box at the base of the diagram. This ‘Limiting Factor’ represents the component of a specie’s life history that best describes suitable habitat. Drivers (green box) and Baseline Ecological Factors (blue box) are placed in levels above. Baseline Ecological Factors include biotic and abiotic factors that are not directly related to the Limiting Factor of a model, but have a strong influence on model outcomes. Drivers are defined as components that are affected by Baseline Ecological Factors, but have a more direct influence on model outcomes. Species-specific conceptual models are evident in the structure of BBNs.

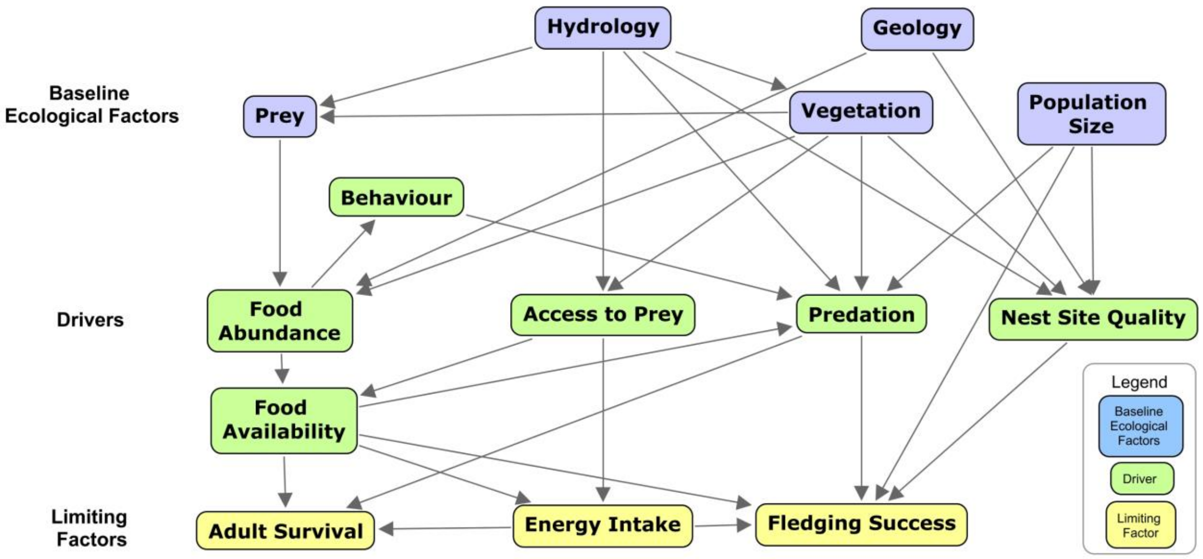

Figure 1. Template conceptual model of waterbird habitat-use in the Coorong, Lower Lakes and Murray Mouth.

Bayesian Belief Networks

Bayesian Belief Networks were deemed the most suitable model for this project because they incorporate the following features:

1. Graphical interface/output (Korb and Nicholson 2010);
2. Ability to incorporate expert knowledge when field data is unavailable (Murray et al. 2009; Korb and Nicholson 2010);
3. Can incorporate new data as it becomes available, and therefore it is relatively straightforward to update model forecasts (Wooldridge and Done 2004); and
4. Represents a system as a series of interactions (Lester and Fairweather 2008).

At this stage, the BBN models have been designed to determine the probability of a particular point in space being considered habitat for a species, given the conditions that the site is experiencing at a point in time and the component of a specie's life history that best describes suitable habitat. Ultimately, the model could be applied to continuous environmental surfaces to determine the area of the CLLMM region that is considered to be suitable habitat under given conditions. This spatial extrapolation should be possible through the development of spatially explicit models that are linked to GIS data if adequate data is available (Liedloff et al. 2009), and will ultimately be important for determining the extent of habitat under different conditions.

The computer program Netica (version 4.16, Norsys Systems Corp., Vancouver, British Columbia) was used for BBN development.

Elicitation protocol

Quantitative data and expert opinion were used to populate Bayesian Belief Networks. Eight experts were invited and chose to participate in an expert elicitation workshop. Information collected before the elicitation workshop provided an understanding of the source and level of each expert's knowledge of CLLMM waterbird ecology and statistics (Appendix 1).

At the time of elicitation, all experts were currently working in roles that were directly relevant to understanding the ecology of waterbirds and/or their prey in the CLLMM (at DEWNR, Flinders University, Adelaide University or as private consultants). Experts had a high level of relevant local experience in bird ecology: four experts had 3-10 years of experience, and another four experts had 11-36 years of experience. Four experts had relevant postgraduate qualifications (Masters or PhD) and another two experts had relevant undergraduate science degrees (with Honours). All experts had been directly involved in monitoring the abundance and distribution of waterbirds and/or their prey in the CLLMM, and had reviewed relevant literature. Statistical knowledge ranged from non-existent to advanced usage, modelling and understanding. The workshop was facilitated by J. O'Connor and P. Pisanu.

The elicitation procedure was as follows (adapted from Burgman et al. 2011).

1. One week before the elicitation workshop, participants were sent preliminary briefing material, which gave an outline of the goals, methods and expectations of the workshop.

2. All experts attended one workshop, in which they were asked questions to elicit the probability of ecological outcomes under specific hypothesised scenarios. These questions were based on relationships that were identified in conceptual models. The elicitation method involved asking for a subjective probability interval, a best estimate, and a credible interval (Bayesian confidence interval). The 22 questions asking for quantities, frequencies and probabilities used the following question format:

    a. Realistically, what is the lowest the value could be?
    b. What is the highest the value could be?
    c. What is your best guess (the most likely value)?
    d. How confident are you that the interval you provided contains the truth (give a value between 50% and 100%)?

3. Experts came to a group consensus on each question during the workshop.

4. The full elicitation record was provided to participants two weeks after the workshop, thus giving participants the opportunity to review recorded information and provide revised answers or comments. The elicitation record then formed the basis for the categorisation of data and probabilities of outcomes within Bayesian models. The population of the Bayesian models with data derived from the experts thus formed a prior model for the response of each waterbird species to environmental change. These priors can then be updated through the analysis of existing datasets and the targeted collection of new data (that is specifically designed to test these priors) (McCarthy 2007).

Evaluation of Models

Sensitivity to findings

Sensitivity to findings analyses were used to identify the sensitivity of a chosen variable to findings (evidence) in other variables. In Netica, sensitivity to findings is quantified as ‘mutual information[1]‘ or ‘entropy’. This project reports on mutual information values, which are relevant for discretised data (noting that even ‘continuous’ variables are discretised in Netica) (e.g. Marcot et al. 2001). The mutual information between the output variable and another node equals the expected reduction in entropy of output variable due to a finding in another node. A mutual information value of zero means that a node is independent of the output variable. For each model, an output node (the ‘limiting factor’) was selected and analysed to determine how much it was influenced by a single finding at each of the other nodes in the network.

Expert Feedback

Two small workshops were conducted in order to obtain expert feedback on all 11 BBN models. The first workshop included two CLLMM bird experts that had previously been involved in our elicitation workshops. Model structure and function were demonstrated to the two experts, who gave feedback on whether these models were a realistic representation of their observations with regard to the relationships/outcomes at the CLLMM site. These models were then revised and presented to two BBN experts in the second workshop. These experts provided feedback and comments on the structure of models, and how to best utilise features within Netica software. The final draft models are those presented in this report encompass feedback and subsequent improvements from two rounds of expert testing.

Species-specific Bayesian Belief Networks

In order to demonstrate the approach described here, draft Bayesian models have been developed for all ten study species. Following the approach used when developing conceptual models, the response variable (the variable that defines ‘habitat’) of these models focused on the critical role of the Coorong/Lower Lakes for the life history of each bird species. First, the ‘limiting factor’ that determines species’ persistence at the site was identified, and then an additional 44 biotic and abiotic factors that are linked to the limiting factor within at least one model were identified (Appendix 1).

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[1] Mutual Information values are used to measure the effect of one variable (X) on another (Y).

Setting key ecological thresholds for waterbirds

Expert opinion and resulting model outputs were used to develop potential Key Ecological Thresholds for each of the ten study species. These thresholds are not analogous to “Limits of Acceptable Change (LAC). LAC are set on extreme minimum and maximum limits that are beyond the levels of natural variation. This approach may be too simplistic to capture smaller shifts in natural variability, (Butcher 2011), so this project instead presents ‘Ideal’, ‘Fair’ and ‘Poor’ thresholds at which key ecological components are likely to affect specific bird species (‘Key Ecological Thresholds’). For each set of thresholds, the following additional information is identified: 1) confidence estimates, and 2) the information source/s (data, expert opinion, model outputs or literature) from which the thresholds were derived. These thresholds may be used to identify ‘management triggers’ at which intervention may be appropriate.

Results Part 1 - Piscivores:

Fairy Tern

The Fairy Tern (*Sterna nereis*) is a piscivorous (fish-eating) resident that breeds in the Coorong between October and February. ‘Fledging success’ was identified as the major limiting factor that affects the persistence of this species within the Coorong and Lower Lakes site. Fairy Terns nest in colonies, therefore this model will apply to fledging success of the colony (not individuals). The response model developed here thus focuses on the probability of fledging success under the alternative environmental conditions described by the model.

The Fairy Tern model is composed of two separate but inter-related BBNs. Model 1 (Figure 2) describes the distribution and abundance of prey fish species (particularly Smallmouth Hardyhead). This model should be run first, and should subsequently be used to spatially forecast the distribution of prey availability.The output of this first model (suitable foraging habitat yes/no) will be used to ‘score’ the availability of fish at each spatial pixel. The second model (Figure 3) describes the physical suitability of the nest site, and how this impacts fledging success.

In these models, Fairy Tern fledging success is determined by: 1) proximity between the nest site and a sufficient density of fish prey, 2) predation, 3) nest site quality, and 4) current Fairy Tern population size.

1. There are two main types of predation that affect Fairy Tern nesting sites:1) predation by avian predators such as silver gulls or ravens (this risk is exacerbated when the primary food source is far from the nest and parents spend more time foraging), and 2) predation by terrestrial predators (that is strongly related to whether the nest site is connected to the mainland).

2. Fairy Terns require a sufficient food source (high density of smallmouth hardyhead fish) within close proximity of their nest site. The model component ‘Proximity of food/nest site (km)’ refers to the distance between a nest site and a sufficient density of fish prey. This node incorporates output (distance between nesting site and food source) from the spatial interpretation of Model 1. Radio-tracking studies have found that foraging trips become less profitable when Fairy Tern parents travel >1km to find food (Paton and Rogers 2009). Therefore we have been able to identify optimal (<1km), suboptimal (1-5km) and unsuitable (>5km) distances between nest sites and sufficient prey densities. Smallmouth Hardyhead

fish prey can be found at salinities of 35 to 110ppt, but are mostly likely to be abundant at salinities of 50-80ppt (Lui 1969; Molsher et al. 1994).

Fairy Terns have also been observed to forage on fish such as small Garfish and Pilchards from the ocean side of Younghusband Peninsula (pers comm D. Paton). However, the Smallmouth Hardyhead have made up the majority (80-90%) of Fairy Tern prey items, since becoming abundant in the Coorong over the past few years (pers comm D. Paton; Ye et al. 2012).

3. Nest site quality is affected by 1) the risk that the site will be inundated with water, and 2) the heterogeneity of nesting habitat (veg & rock cover). Fairy terns always form ‘scrapes’ (nests) in sand, but prefer to be surrounded by some rock and vegetation (undefined quantity) for protection of young once they leave the nest scrape.

4. The most recent Fairy Tern population size count (within 1 year) is a good indicator of past conditions (local) over the past few years. Therefore if the population size is large, then there is a good chance that local environmental conditions have been good over the past few years, and there will be a higher chance of high fledging success in the current year.

Figures 2 and 3 show forecasts for Fairy Tern fledging success under ‘ideal’ conditions. Information has been entered into the following BBN nodes: 1) Salinity, and 2) Water Depth (Model 1, Figure 2), and 3) Veg and Rock Cover, 4) Habitat Inundation, 5) Connection to Mainland, and 6) Population size (Model 2, Figure 3). Based on the probability distributions entered for ‘ideal conditions’ (Figure 2), there is a 75.9% probability of foraging habitat being suitable at a given spatial location. Model 2 (Figure 3), gives a 62.2% chance of high fledging success under ‘ideal’ conditions. Additional information, such as knowledge of other node states, can be entered into either model to update the probability of foraging habitat suitability and fledging success for Fairy Terns.

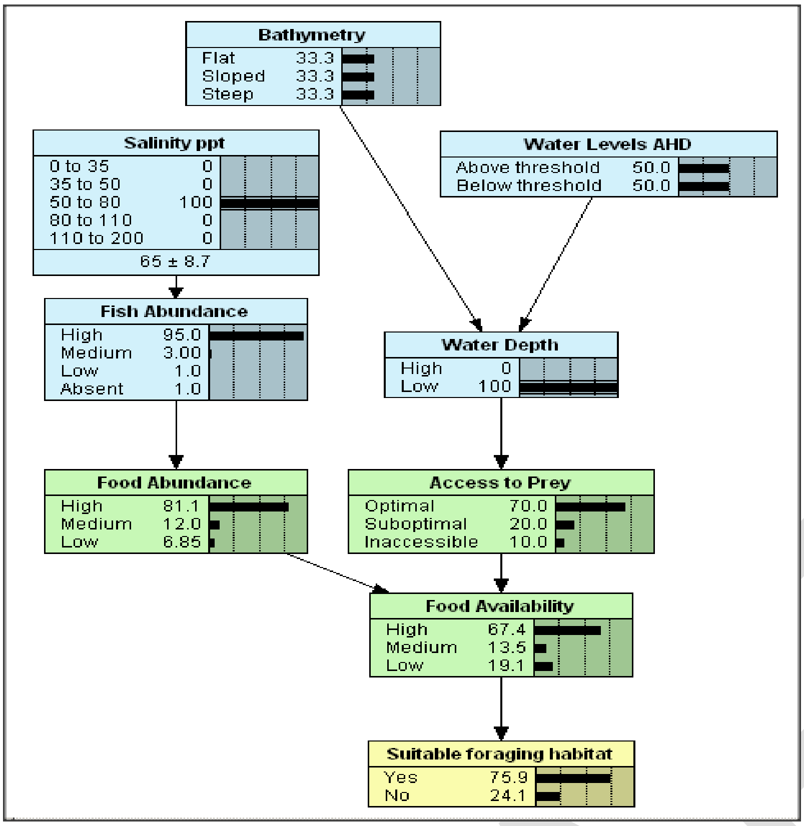


Figure 2. Fairy Tern BBN part 1: Spatial analysis of potential foraging habitat in the Coorong. This model shows ‘ideal’ conditions of salinity and water depth.

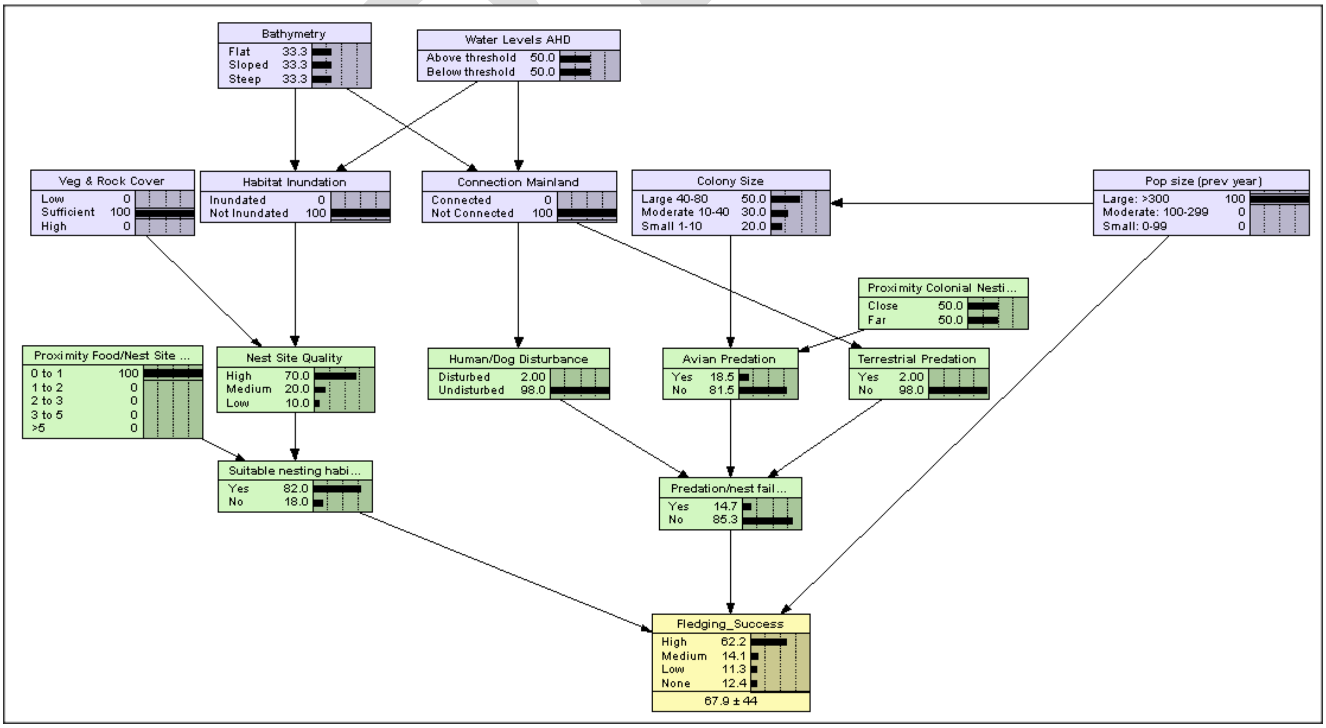


Figure 3. Fairy Tern BBN part 2: nest site factors under ‘ideal’ conditions

Sensitivity Analyses

Table 1 shows the sensitivity of the ‘Suitable Foraging Habitat’ output node (Model 1) to findings at other nodes in the network. The nodes that represent Food Availability and Abundance have the largest impact on the suitability of a given site (spatial pixel)as Fairy Tern foraging habitat. Ideally, a measure of fish abundance and availability should be entered into the model, however information can be input into the salinity and water depth nodes at a minimum. However, this model would greatly benefit from an additional model to predict fish distribution and abundance (or at least a sensitivity analysis to show that the best predictors of food availabilility are salinity and water level).

Table 1 Sensitivity of the ‘Suitable foraging habitat’ node to findings at other nodes in the Fairy Tern network (Model 1). Variables are shown in descending order of strength.

Parameter	Mutual Information
Suitable Foraging Habitat	0.98392
Food Availability	0.33126
Food Abundance	0.10956
Fish Abundance	0.08849
Access	0.07999
Salinity ppt	0.05495
Water Depth	0.02087
Water Levels AHD	0.00727
Bathymetry	0.00032

Table 2 shows that the parent nodes ‘Suitable Nesting Habitat’, and ‘Predation’ have the strongest influence on Fairy Tern fledging success in Model 2. Information in these nodes, or their immediate parents will therefore improve the model’s ability to forecast values of fledging success. The following nodes are considered independent of the output node (fledging success), because they have no prior information in their conditional probability tables: ‘Proximity to Colonial Nesting Species’, ‘Bathymetry’, and ‘Water Levels AHD’.

Table 2. Sensitivity of the ‘Fledging Success’ node to findings at other nodes in the Fairy Tern network (part 2) . Variables are shown in descending order of influence.

Node	Mutual Information
Fledging Success	1.59405
Suitable nesting habitat	0.15773
Predation	0.17561
Terrestrial Predation	0.11992
Connection to Mainland	0.10163
Human Disturbance	0.04656
Proximity to Food Source	0.04028
Avian Predation	0.0231
Colony Size	0.01207
Population Size	0.03462

Nest Site Quality	0.00297
Veg Rock Cover	0.00065
Habitat Inundation	0.00039
Proximity Colonial Nesting Species	0
Bathymetry	0
Water Levels AHD	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (at a minimum).

Fairy Tern Model 1

- Salinity
- Water Depth
- Fish Abundance

Fairy Tern Model 2

- Veg and Rock Cover
- Habitat inundation
- Connection to mainland
- Population size
- Proximity of food source to nest site

Other considerations

Most of the components that directly or indirectly impact on Fairy Tern nesting can have an ‘all or nothing’ effect on fledging success. For example, if a Fairy Tern nesting site is connected to the mainland, then there is a 95% chance that nests will be predated by terrestrial predators (mainly foxes). High fledging success has only ever been recorded when Fairy Terns nest on islands (Paton and Rogers 2009; DENR 2012).

Fledging success may also be impacted by nesting failure if eggs or chicks are exposed to unfavourable climatic conditions; the risk of which is exacerbated when the primary food source is far from the nest and parents therefore spend more time foraging.

Knowledge gaps:

A number of knowledge gaps regarding Fairy Tern are apparent:

- This model makes a critical assumption that breeding responses to food density exhibit a threshold (‘all-or-nothing’) response. While this has been demonstrated for other seabird species (Cury et al. 2011), this threshold model needs to be tested for Fairy Tern in the Coorong.

- While there is some evidence of the impact that the distance between nest sites and suitable foraging sites has on breeding success, these need to be better described, particularly under different food availability conditions (linked to previous knowledge gap)
- More information is required on the impact of water levels on Fairy Tern foraging. It was assumed that access to prey is hindered by high water levels, or at least Fairy Terns prefer to forage over shallow water rather than deep water. The quantitative thresholds for water depth remain unknown.
- It is not known whether the presence of other colonial nesting birds may increase or decrease predation of Fairy Tern nests by avian predators (e.g. gulls), or facilitate breeding by these obligate colonial nesters (e.g. other tern species).
- There is currently a lack information on water levels (AHD) and bathymetry, and how these factors determine the connection of nest sites to the mainland or the risk of nest-site inundation

Key Ecological Thresholds: Fairy Tern

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Salinity*	Expert Opinion/Data	ppt	50-80	35-50, 80-110	<35 or >110	95%
Proximity of nest-site to food source: fish	Expert Opinion/Data	km	0-1	1-3	>3	95%
Habitat inundation (of potential nest site)	Expert Opinion/Data	Yes/no	Not inundated	N/A	Inundated	95%
Connection of nest-sites to mainland	Expert Opinion/Data	Yes/no	Not connected (Island)	N/A	Connected	95%

* effect on fish distribution and abundance

Common Greenshank

The Common Greenshank *(Tringa nebularia)* is an international migrant that visits the Coorong/Lower Lakes in the Austral summer. Greenshank are thought to feed predominantly on fish in the CLLMM, but also prey on macroinvertebrate prey. ‘Energy Intake’ (non-breeding) is identified as the main limiting factor for this species in the CLLMM.

‘Energy Intake’ is directly affected by 1) ‘Macroinvertebrates caught per minute’, and 2) ‘Fish caught per minute’.

1. The amount of macroinvertebrate prey items caught per minute depends on: 1) access to habitats where macroinvertebrates occur (that is largely determined by water depth), and 2) macroinvertebrate abundance. In the Greenshank model, access to macroinvertebrate prey

is ‘ideal’ when shoreline water levels are <6cm. While macroinvertebrate abundance in this model is driven by salinity, a more comprehensive macroinvertebrate response model (or models) is required. For the purposes of this model, there is a >88% probability of high macroinvertebrate abundance when salinity is between 20-90 ppt (Figure 4; Dittmann et al. 2011; Keuning et al. 2012)

2. The number of fish prey items caught per minute is determined by 1) fish abundance, and 2) access to fish. The salinity and prey access (water depth) thresholds differ between fish and macroinvertebrates. Greenshank predominantly forage on fish in the CLLMM (pers comm D. Rogers, D. Paton). As a food resource, fish are a higher energy-density prey than other local prey alternatives, such as macroinvertebrates (Furness 2007; Keuning 2011).

Figure 4 shows an application of the Greenshank Model under ‘ideal’ conditions.

Information has been entered into the following nodes: 1) Salinity, 2) Water depth (shoreline), and 3) Turbidity. Based on the probability distributions entered for ‘ideal conditions’ (Figure 12), there is a 62.5% chance of high energy intake at a given spatial pixel. Additional information can be entered into either model, which will update the probability of energy intake for Greenshank.

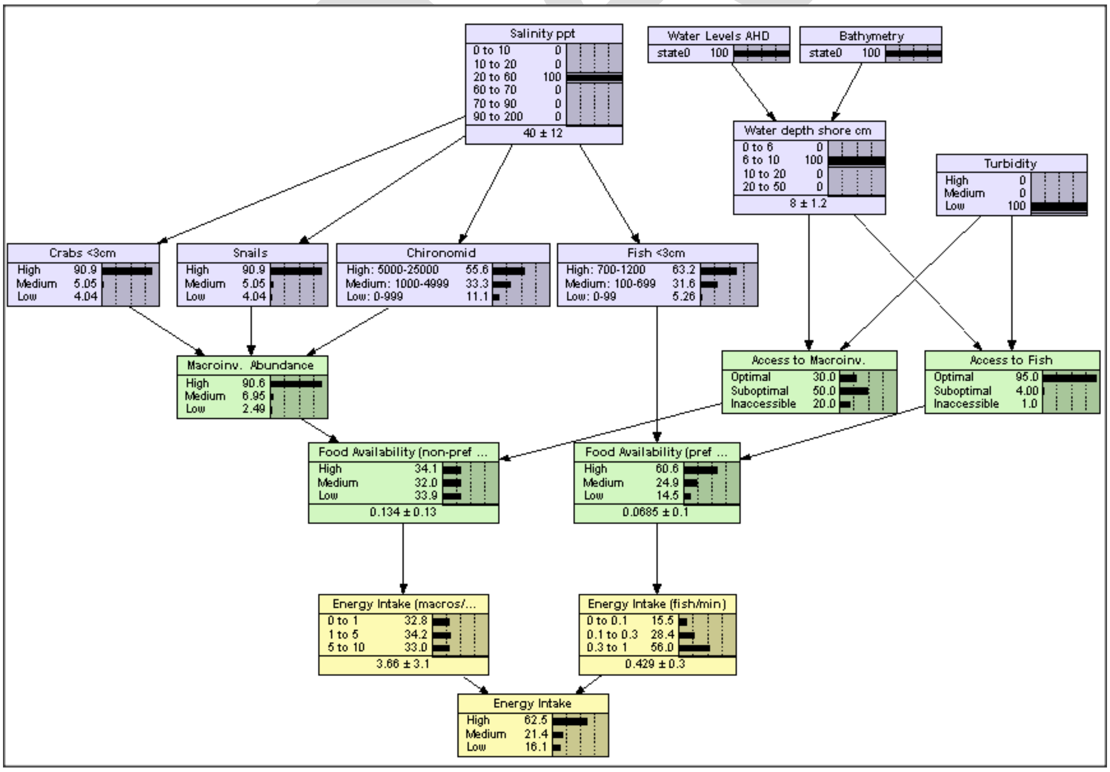


Figure 4. Greenshank Model under ‘ideal’ conditions.

Sensitivity Analyses

Table 3 shows that the abundance and availability of fish prey has the strongest influence on Greenshank energy intake. Information in these nodes (Energy Intake (fish) and Food Availability (preferred prey)), or their immediate parents will therefore improve the model's ability to forecast overall Greenshank energy intake. The following nodes are considered independent of the output node (Energy Intake), because they have no prior information in their conditional probability tables: 'Bathymetry', and 'Water Levels AHD'.

Table 3. Sensitivity of the 'Energy Intake' node to findings at other nodes in the Common Greenshank network. Variables are shown in descending order of influence.

Node	Mutual Information
Energy Intake	1.41043
Energy Intake (fish)	0.52337
Food Availability (preferred prey)	0.35478
Access to Fish	0.12905
Energy Intake (macroinvertebrates)	0.11331
Food Availability (non-preferred prey)	0.09412
Access to Macroinvertebrates	0.0739
Water Depth	0.06815
Fish	0.05579
Turbidity	0.03235
Salinity	0.02312
Chironomid	0.00807
Snails	0.00538
Crabs	0.00538
Macroinvertebrate Prey Abundance	0.17
Bathymetry	0
Water Levels AHD	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum***)***

- Salinity
- Water Depth (shore)
- Turbidity
- Fish Abundance

Knowledge gaps:

A number of knowledge gaps regarding Greenshank are apparent:

- There is little information on prey types consumed by Greenshank under any ecological conditions. It would be difficult to identify prey consumed via foraging observations as prey is commonly captured 'when the bill (is) buried in sediment or because individuals (are) foraging in water' (Keuning 2011).
- The relative contribution of each food source to their diet is unknown. Fish prey has been identified as the most important food source due to its high energy content. The

contribution of macroinvertebrate prey to the overall diet is negatively associated with the number of fish caught per minute

- The relationship between access to prey and water depth is not well known for this species (absolutely, and relative to other shorebirds, e.g. Red-necked Stint and Sharp-tailed Sandpiper; Rogers and Paton 2009)

Key Ecological Thresholds: Common Greenshank

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Salinity *	Expert Opinion/Data	ppt	20-60	0-10, 70-90	>90	95%
Water depth (shoreline) **	Expert Opinion	cm	0-10	10-20	>20	90%
Turbidity	Expert Opinion	NTU	>15	15-30	>30	80%

* effect on fish and chironomid abundance (main prey)
**access to fish and chironomid prey

Results Part 2 - Shorebirds

Sharp-tailed Sandpiper

The Sharp-tailed Sandpiper (*Calidris acuminata*) is an international migrant that visits the CLLMM and other areas of southern Australia to feed predominantly on macroinvertebrate prey over summer. Up to 20% of the global population of Sharp-tailed Sandpipers has been recorded in the CLLMM at a given point in time (Paton 2005; O'Connor et al. 2012). This species uses the site to gain 'Adequate energy stores for migration'.

The ability of this species to gain 'Energy for Non-breeding Activities' is directly affected by 1) food abundance, and 2) access to prey.

1. While the abundances of all four main prey categories are affected by salinity, each prey species has a different known salinity tolerance. In the model, salinity has been categorised into ranges that are biologically relevant for the broad range of prey types. Polychaetes and amphipods have been grouped into one component due to their similar salinity and sediment size requirements (both groups of species are infauna). Freshwater and saline Chironomid larvae have been split into two components (Chironomid fresh and *Tanytarsus* (saline species)) due to their different salinity tolerances.

2. The ability of Sharp-tailed Sandpipers to access prey is limited by 1) water depth and 2) % cover by Macroalgal blooms. Sharp-tailed sandpipers have short bills and legs, which limits their ability to forage on macroinvebrate prey (Polychaete/Amphipod, Chironomid & *Tanytarsus*) in or on top of sediment (Paton 2010; Keuning 2011). The water depth at which Sharp-tailed Sandpipers can access macroinvertebrate prey is 0.1-2cm, although they have been observed to forage at lower frequencies (and with limited success – Rogers and Paton 2009) in water depths above and below this range. Macroalgal cover (%cover) over sediment can restrict the ability of birds to access food, and can also have a negative impact on Polychaete/Amphipod prey if it causes anoxic conditions within sediment.

Figure 5 shows forecasts for the ability of Sharp-tailed Sandpipers to gain "adequate energy stores for migration" under "ideal" conditions of: Water Depth, Macroalgal Cover, Sediment Size, and Salinity respectively. Inputting data into these four nodes (which are easily measurable), influences the probabilities of different scenarios in six other nodes. Based on the probability distributions entered for "ideal conditions" (Figure 5), there is a 56% chance of gaining adequate energy stores for migration. Additional information can be entered into the model, which will update the probability of model outcomes.

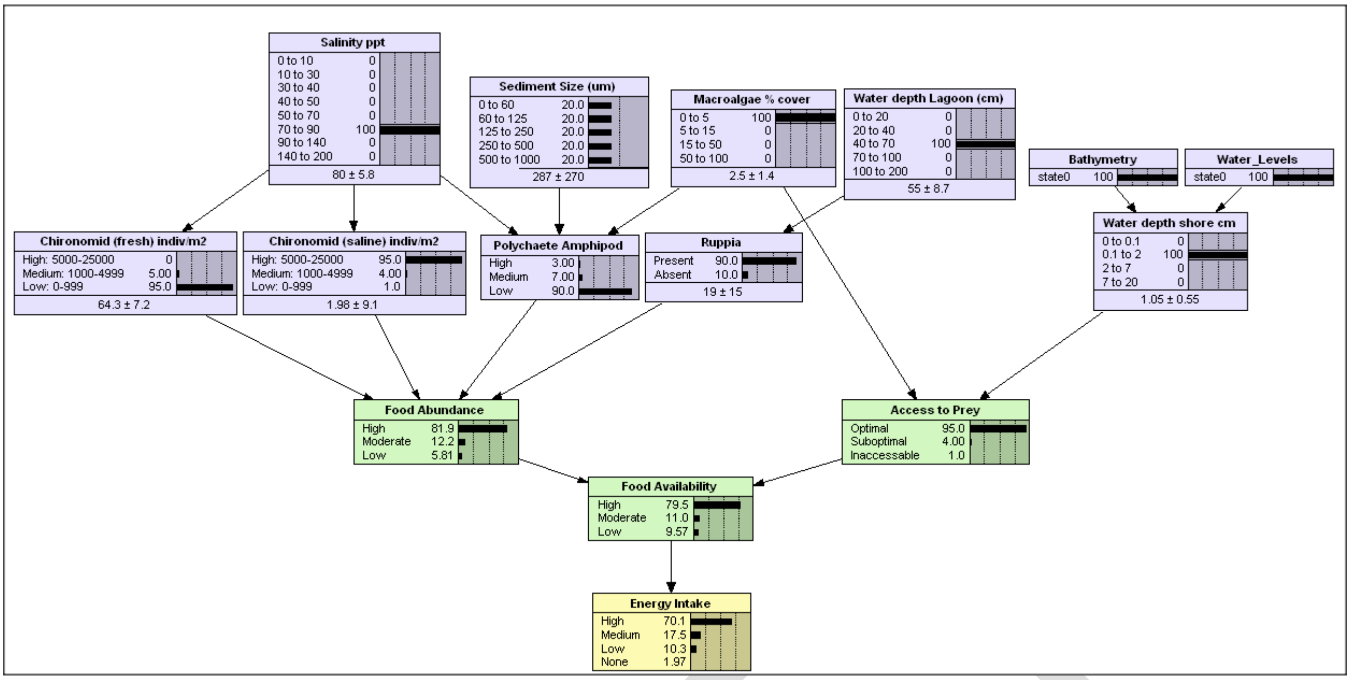


Figure 5. Sharp-tailed Sandpiper under 'ideal' conditions

Sensitivity Analyses

Table 4 shows that the abundance and availability of prey, and shoreline water depth have the strongest influence on Sharp-tailed Sandpiper energy intake. Information in these nodes or their immediate parents will therefore improve the model's ability to forecast overall sandpiper energy intake. The following nodes are considered independent of the output node (Energy Intake), because they have no prior information in their conditional probability tables: 'Bathymetry', and 'Water Levels AHD'.

Table 4. Sensitivity of the 'Energy Intake' node to findings at other nodes in the Sharp-tailed Sandpiper network. Variables are shown in descending order of influence.

Node	Mutual Information
Energy Intake	1.8046
Food Availability	0.50965
Access to Prey	0.1579
Food Abundance	0.09774
Water Depth cm	0.07237
Salinity	0.02369
Macroalgae % cover	0.01889
Chironomid (saline)	0.01785
Polychaete & Amphipod	0.00782
Chironomid (fresh)	0.00408
Sediment Size	0.00039
Ruppia	0.00021
Water Depth	0.00011
Water Levels AHD	0
Bathymetry	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum***):***

- Salinity
- Sediment Size
- Water Depth Shore
- Water Depth Lagoon
- Macroalgae % cover

Knowledge gaps:

A number of knowledge gaps regarding Sharp-tailed Sandpiper are apparent:

- The relative contribution of each food source to Sharp-tailed Sandpiper diet is unknown. Expert opinion indicates that overall food abundance may be high when there is a high abundance of at least one macroinvertebrate prey type (Polychaete/Amphipod, Chironomid, or Tanytarsus). Submerged veg is likely to be the least important component of the bird's diet. The main species of 'submerged veg' food is assumed to be *Ruppia tuberosa* in the Coorong. Even here, however, the contribution that the different components of *R. tuberosa* (seeds, vegetation, turions) make to the non-breeding diet of Sharp-tailed Sandpiper is unknown.

Key Ecological Thresholds: Sharp-tailed Sandpiper

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Salinity *	Expert Opinion/Data	ppt	70-90	<70, 90-140	>140	95%
Water depth (shoreline) **	Expert Opinion	cm	0.1-2	0-0.1,2-7	>7	90%
Macroalgal cover (% cover over sediment)	Expert Opinion	% cover	0-50	5-50	>50	60%
Sediment Size**	Expert Opinion/Data	um	125-250	60-125, 250-500	<60, >500	95%

* effect on macroinvertebrate abundance (main prey)
**for polychaete and amphipods

Red-necked Avocet

The Red-necked Avocet (*Recurvirostra novaehollandiae*) is an Australian resident that uses the site as a 'drought refuge'. 'Adult Survival' is identified as the major limiting factor that affects the persistence of this species within the Coorong and Lower Lakes site.

Adult survival is directly affected by: 1) Food Availability, and 2) Access to Prey.

1. Food availability is a function of ‘Food Abundance’ and ‘Access to Prey’. Overall food abundance is affected by the individual abundances of four main prey types. Chironomids are likely to be the primary food source for Red-necked Avocets, and have a greater effect on the overall measure of ‘Food Abundance’. In this model, Brine Shrimp abundance has little impact on overall food abundance, because in the past, Red-necked Avocets have declined in numbers even when Brine Shrimp are abundant. Epibenthic macroinvertebrates (e.g. Amphipods) are also included in this model, but similarly have a smaller effect on overall food abundance, as they are assumed to be a non-preferred food source. Avocets will also feed on small schooling fish (<3cm long), the abundance of which was based on thresholds for Small-mouthed Hardyhead (this species is common in the Coorong).

2. ‘Access to Prey’ is determined by water depth. The optimal foraging strategy for Red-necked Avocets is to forage whilst walking/wading through shallow water. However, this species can also forage in deeper water by swimming and ‘up-ending’ to reach prey within the water column. Prey is likely to be inaccessible in water that is greater than 1.5 metres deep. Figure 6 show forecasts for Red-necked Avocets under “ideal” conditions of: Salinity and water depth. Based on the probability distributions entered for “ideal conditions” (Figure 6), there is a 64.9% chance of high adult survival. Additional information can be entered into the model, which will update the probability of model outcomes.

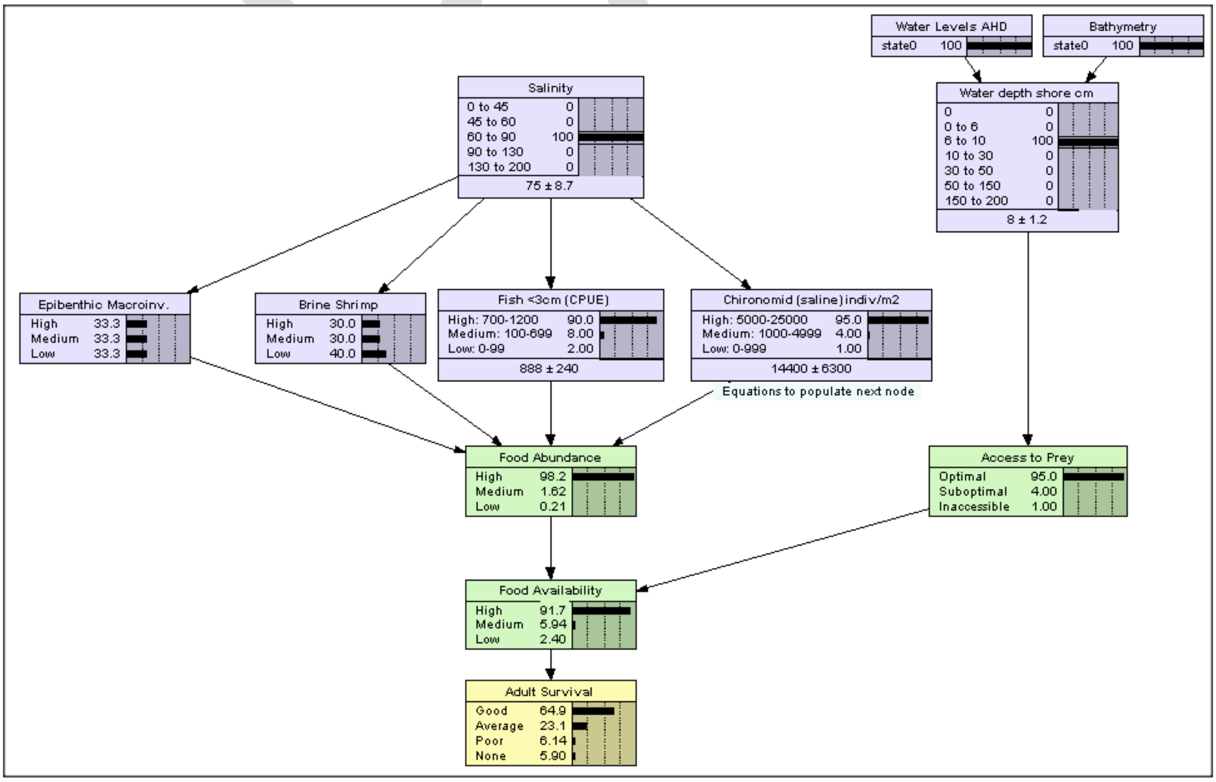


Figure 6. Red-necked Avocet Model under ‘ideal’ conditions

Sensitivity Analyses

Table 5 shows that the nodes ‘Food Availability’, ‘Access to Prey’ and ‘Water Depth (shore)’ have the strongest influence on adult survival in the Red-necked Avocet. Information in these nodes or their immediate parents will therefore improve the model’s ability to forecast overall avocet energy intake. The following nodes are considered independent of the output node (Adult Survival), because they have no prior information in their conditional probability tables: ‘Bathymetry’, and ‘Water Levels AHD’.

Table 5. Sensitivity of the ‘Adult Survival’ node to findings at other nodes in the Red-necked Avocet network. Variables are shown in descending order of influence.

Node	Mutual Information
Adult Survival	1.94963
Food Availability	0.45742
Access to Prey	0.21234
Water Depth Shore	0.12029
Food Abundance	0.07389
Chironomid	0.02163
Salinity	0.0202
Fish	0.01203
Brine Shrimp	0.00134
Epibenthic Macroinvertebrates	0.00037
Bathymetry	0
Water_Levels AHD	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum***)***

- Salinity
- Sediment Size
- Water Depth Shore
- Water Depth Lagoon
- Macroalgae % cover
- Chironomid Abundance

Other considerations

Red-necked Avocets do not breed in the Coorong on a regular basis, but may commence breeding activity if prey abundance is very high.

Knowledge gaps

A number of knowledge gaps regarding Red-necked Avocet are apparent:

Prey

- The relative contribution of each food source to their diet is unknown. Expert opinion indicates that this species prefers to eat chironomids, and can switch to fish and other macroinvertebrates according to availability. However, there are very limited data to support these assumptions.

Key Ecological Thresholds: Red-necked Avocet

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Salinity *	Expert Opinion/Data	ppt	60-90	<60, 90-130	>130**	95%
Water depth (shoreline) **	Expert Opinion	cm	6-10	0.1-6, 10-150	0, >150	90%

* effect on fish and chironomid abundance (main prey)
**But can feed on brine shrimp

Scenario testing

Scenario testing was conducted in order to test the outputs of this model (Appendix 3). Abundance and location data for Red-necked Avocets, Chironomids, and hardyhead fish were compared to test the relationships outlined in the model. Relative comparisons show that the trends between the fish and macroinvertebrate monitoring datasets and the predictive outputs of the model are generally consistent. For example, Red-necked Avocet abundance was high when there was high availability of fish or chironomids at the same site (Appendix 3). *NB: I am working on similar comparisons for other species and how to best present the outputs*

Results Part 3 - Wading Birds

Great Egret

The Great Egret (*Ardea alba*) is a piscivorous (fish-eating) species that mainly uses Lower Lakes habitats for foraging and other non-breeding activities (although there are some historic breeding records from Lake Alexandrina). The movement patterns of Lower Lakes populations are largely unknown, though this species is known to migrate to other countries in Australasia (e.g. New Zealand and Papua New Guinea) (Marchant and Higgins 1990). ‘Energy Intake’ is identified as the major limiting factor that affects the persistence of this species at the CLLMM site.

Energy Intake is directly affected by ‘Food Availability’, which is a function of:1) Fish Abundance, and 2) Access to Prey (fish).

1. In this model, fish abundance is impacted by water depth, salinity, and vegetation cover. The ‘ideal’ water depth for foraging is 10-25cm (Figure 7). Salinity levels are most likely to support abundant freshwater fish at <10ppt (Figure 7). Low-Medium cover by emergent and submerged vegetation will facilitate access to prey (Figure 7).

2. Access to prey (fish) is affected by water depth (categories based on egret leg length and therefore water depth at which they can wade through), and whether there is a suitable level of cover by emergent and submerged vegetation. A certain level of vegetation cover increases egret foraging access by allowing the bird to remain hidden from prey. Too much vegetation cover will prevent egrets from wading (foraging) through the area.

Figure 7 show forecasts for the Great Egret under “ideal” conditions of: Salinity, water depth and emergent veg % cover. Based on the probability distributions entered for “ideal conditions” (Figure 7), there is a 69.2% chance of high energy intake. Additional information can be entered into the model, which will update the probability of model outcomes.

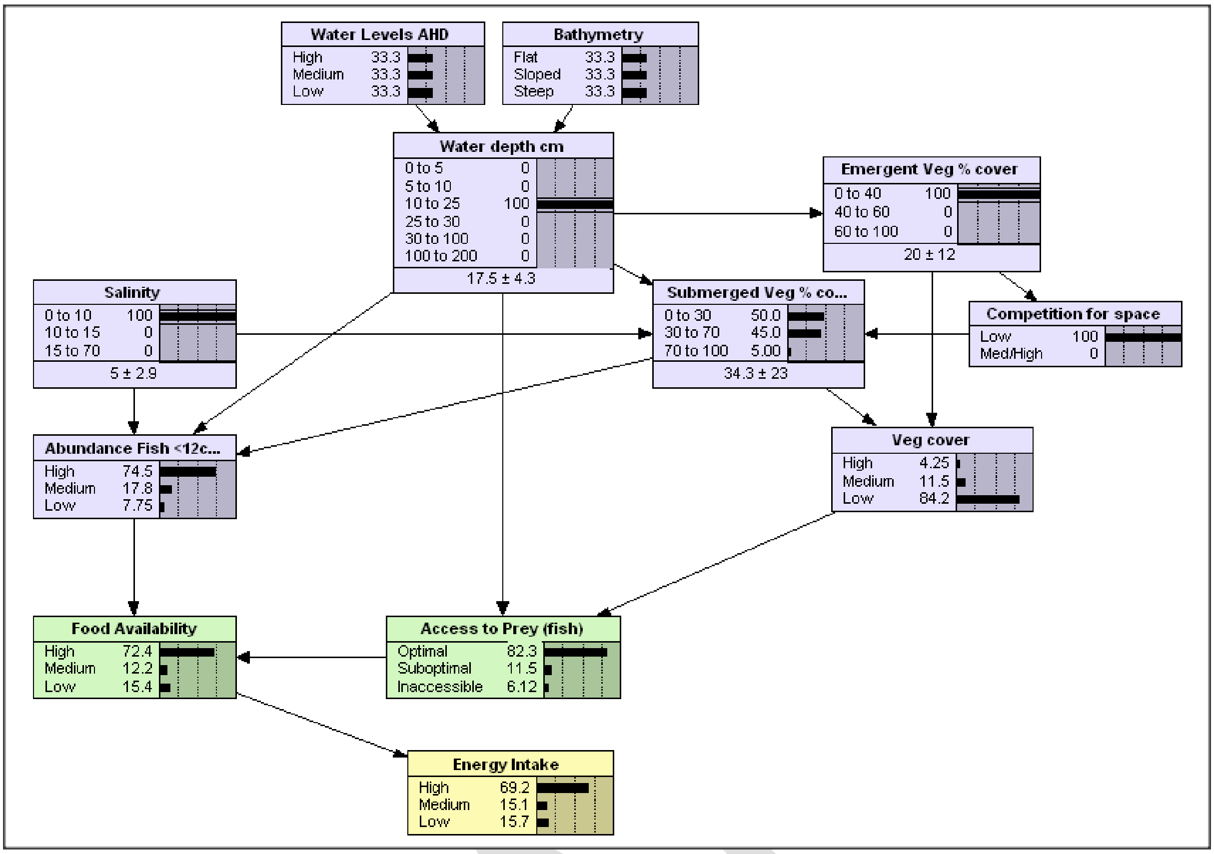


Figure 7. Great Egret Model under 'ideal' conditions

Sensitivity Analyses

Table 6 shows that the nodes 'Food Availability', 'Access to Fish' and 'Fish Abundance' have the strongest influence on energy intake for the Great Egret. Information in these nodes or their immediate parents will therefore improve the model's ability to forecast overall egret energy intake. The following nodes are considered independent of the output node (Energy Intake), because they have no prior information in their conditional probability tables: 'Bathymetry', and 'Water Levels AHD'.

Table 6. Sensitivity of the 'Energy Intake' node to findings at other nodes in the Great Egret network. Variables are shown in descending order of influence.

Node	Mutual Information
Energy Intake	1.52935
Food Availability	1.20415
Access to Fish	0.34807
Fish Abundance	0.26319
Water Depth	0.09109
Veg cover	0.0396
Emergent Veg % cover	0.0077
Submerged Veg % cover	0.00608
Competition for space	0.00481
Salinity	0.00024
Water levels AHD	0

Bathymetry	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum***):***

- Salinity
- Water Depth Shore
- Fish Abundance

Other considerations

Great Egrets are not active foragers and mainly use a ‘sit and wait’ or ‘walk slowly’ strategy to forage for fish prey. Therefore they expend little energy to catch small numbers of high quality food (fish).

Knowledge gaps

A number of knowledge gaps regarding Great Egret are apparent:

Prey

- There is no known explicit data on preferred fish prey species that are consumed by egrets in the Lower Lakes. Prey size (<12cm long) is inferred from what the bird is physiologically able to consume, and from past studies looking at fish remains near nesting sites (Close et al. 1982).

Key Ecological Thresholds: Great Egret

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Salinity*	Expert Opinion	ppt	?	0-70	>70	90%
Reed cover	Expert Opinion	% cover	5-10	0-5, 10-60	>60	80%
Water depth (shoreline)	Expert Opinion	cm	10-25	5-10, 25-30	<5, >30	80%

* effect on fish abundance

Royal Spoonbill

The Royal Spoonbill (*Platalea regia*) is a macroinvertebrate and fish-eating species that mainly uses Lower Lakes and Northern Coorong habitats. ‘Energy Intake’ is idnetified as the major limiting factor that affects the persistence of this species at the site. This model should be applied to habitats within the Lower lakes and Northern Coorong.

Energy Intake (whilst foraging) is directly affected by: 1) Food Abundance, and 2) Access to Prey.

1. Royal Spoonbills are active foragers and capture prey by sweeping their bills through water. Spoonbills are mainly able to capture macroinvertebrate and fish prey items using this method. In this model, all three prey types are given equal weighting to the overall ‘Food Abundance’ node. Fish abundance is unaffected by changes in salinity because of the potentially high number of species with different salinity tolerances that are taken as prey (between the freshwater lakes and saline Northern Coorong).

2. Access to prey (fish) is affected by water depth (categories based on egret leg length and therefore water depth at which they can wade through), and whether there is a suitable level of cover by emergent and submerged vegetation. A certain level of vegetation cover increases spoonbill foraging access by allowing the bird to remain hidden from prey. Too much vegetation cover will prevent egrets from wading (foraging) through the area.

Figure 8 show forecasts for the Royal Spoonbill under “ideal” conditions of: Salinity and water depth. Based on the probability distributions entered for “ideal conditions” (Figure 6), there is a 60.8% chance of high energy intake. Additional information can be entered into the model, which will update the probability of model outcomes.

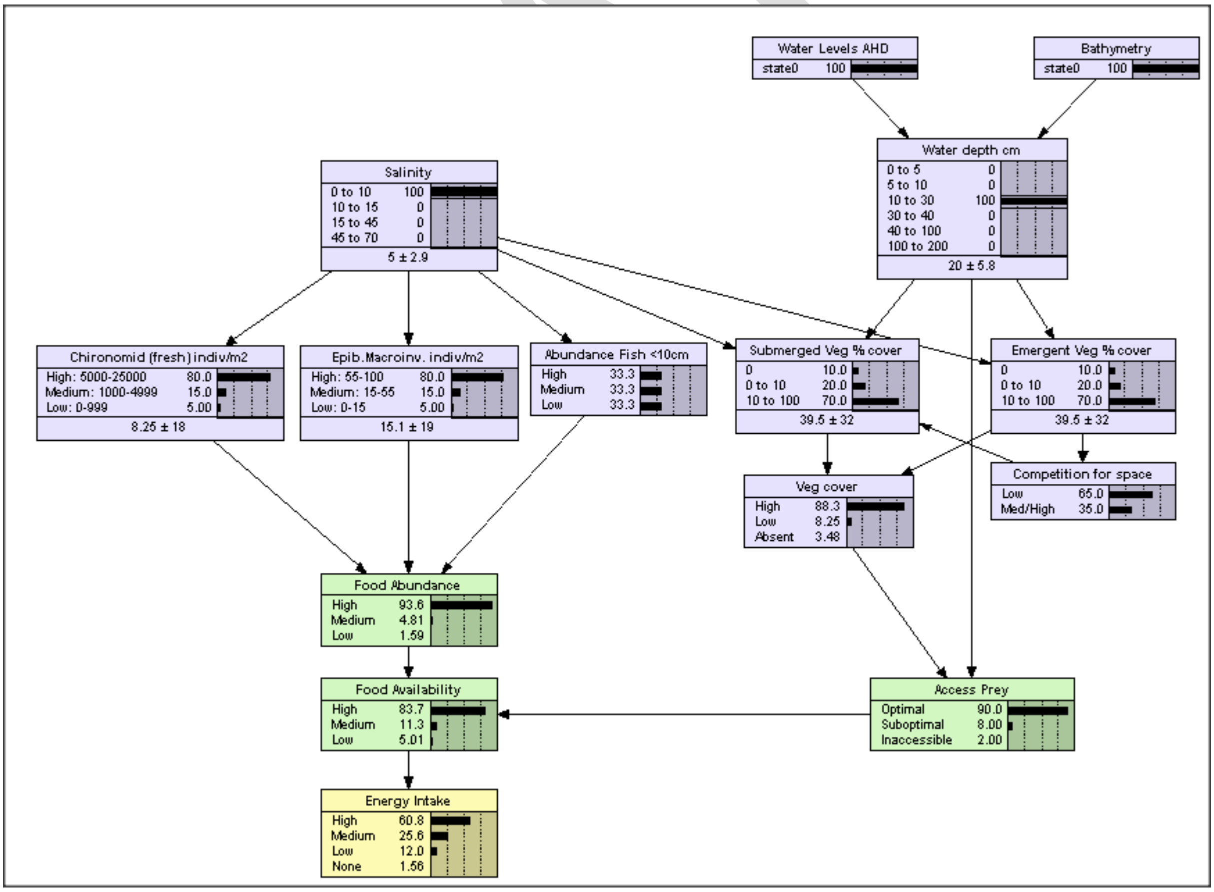


Figure 8. Royal Spoonbill Model under ‘ideal’ conditions

Sensitivity Analyses

Table 7 shows that the nodes ‘Food Availability’, ‘Access to Prey’ and ‘Water Depth’ have the strongest influence on energy intake for the Royal Spoonbill. Information in these nodes or their immediate parents will therefore improve the model’s ability to forecast overall spoonbill energy intake. The following nodes are considered independent of the output node (Energy Intake), because they have no prior information in their conditional probability tables: ‘Bathymetry’, and ‘Water Levels AHD’.

Table 7. Sensitivity of the ‘Energy Intake’ node to findings at other nodes in the Royal Spoonbill network. Variables are shown in descending order of influence.

Node	Mutual Information
Energy Intake	1.7935
Food Availability	0.40116
Access to Prey	0.21261
Water depth cm	0.15836
Food Abundance	0.03088
Chironomid	0.01068
Emergent Veg % cover	0.01064
Veg Cover	0.01052
Salinity	0.00961
Epibentic Macroinvertebrate	0.00902
Submerged Veg % cover	0.00659
Competition for Space	0.00351
Fish Abundance	0.00058
Water level AHD	0
Bathymetry	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum***):***

- Salinity
- Water Depth Shore

Other considerations

The output node ‘Energy Intake’ may be difficult to measure, so it is recommended that the percentage of time that these birds spend foraging could be used as a surrogate measure.

Knowledge gaps

A number of knowledge gaps regarding Royal Spoonbill are apparent:

- There is no explicit data on prey species taken by Royal Spoonbills at this site. However, it is broadly known that this species consumes fish that are <10cm long (HANZAB). Howard and Lowe (1984) also found that the macroinvertebrate

Macrobrachium intermedium made up 70 (NB) to 88%(B) of Royal Spoonbill diet in southeastern Australia. Further studies into the local diet of Royal Spoonbills are recommended.

- The 'Optimal' foraging depth is unknown for this species. In this model, the optimal foraging depth (0.4m) was 'inferred' based on average leg length.

Key Ecological Thresholds: Royal Spoonbill

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Salinity*	Expert Opinion/Model outputs	ppt	0-10	10-45	>45	80%
Reeds	Expert Opinion	% cover	0	0-10	>10	95%
Submerged Veg	Expert Opinion	% cover	0	0-10	>10	95%
Water depth (shoreline)	Expert Opinion	cm	0	1-10, 30-40	>40	95%

* effect on prey abundance

Results Part 4 -Herbivores

Black Swan

The Black Swan (*Cygnus atratus)* is an Australian resident that feeds on submerged vegetation across the system. This species breeds within the Lower Lakes, but also utilises Coorong habitats for foraging (mainly on *Ruppia*). Black Swan historically bred on the Coorong, but have not done so for some time (O'Connor 2013), and so breeding is not considered for the Coorong model. 'Adult Survival' and 'Nest Site Quality' were identified as the major limiting factors that affect the persistence of this species in the Southern Coorong and the Lower Lakes respectively.

Freshwater model:

Nest Site Quality is directly affected by: 1) Food Availability, 2) Predation, and 3) Nest Site Quality

1. Food availability is influenced by submerged vegetation (food) abundance and access to prey. Access to prey decreases under conditions of high emergent vegetation cover and increasing depth between the water surface and the maximum height of submerged vegetation.

2. Nest predation increases when nest sites are connected to the mainland (allows human/predator access to nests).

3. Nest site quality is influenced by the availability of supportive substrate, such as reed material (emergent vegetation) to construct and support nests. Black Swans will usually choose to nest in low energy environments (e.g. low wave action), or in elevated areas of high energy environments.

Figure 8 show forecasts for the Black Swan (freshwater) under "ideal" conditions of: Salinity, Water Depth and Connection to Mainland. Based on the probability distributions entered for "ideal conditions" (Figure 6), there is a 46% chance of high fledging success. Additional information can be entered into the model, which will update the probability of model outcomes.

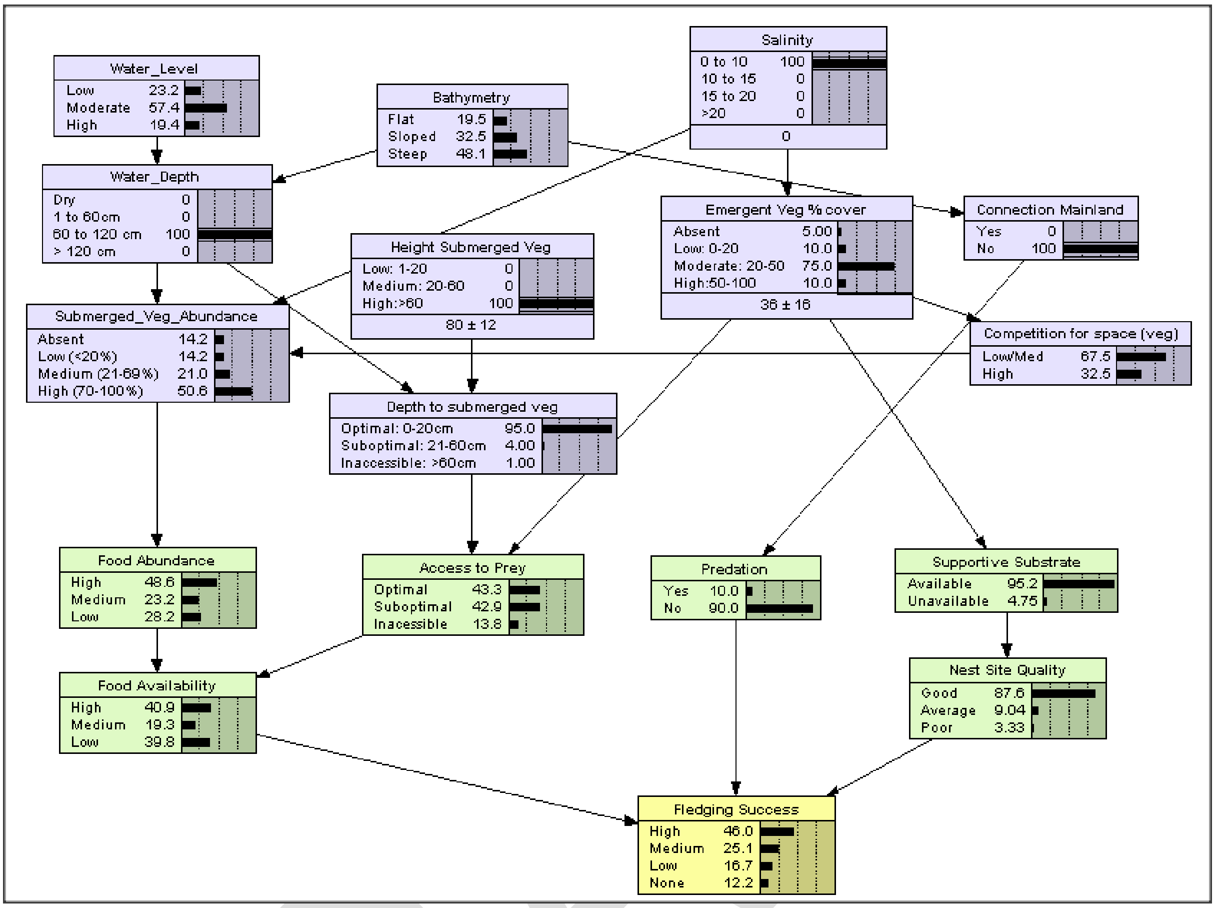


Figure 9. Freshwater Black Swan Model under 'ideal' conditions

Sensitivity Analyses

Table 8 shows that the nodes 'Predation, 'Connection to Mainland and 'Food Availabilityhave the strongest influence on energy intake for the Black Swan. Information in these nodes or their immediate parents will therefore improve the model's ability to forecast overall swan energy intake. The following nodes are considered independent of the output node (Fledging Success), because they have no prior information in their conditional probability tables: 'Bathymetry', and 'Water Levels AHD'.

Table 8. Sensitivity of the 'Energy Intake' node to findings at other nodes in the Black Swan (freshwater) network. Variables are shown in descending order of influence.

Node	Mutual Information
Fledging Success	1.86216
Predation	0.34284
Connection to Mainland	0.14938
Food Availability	0.11614
Nest Site Quality	0.05671
Food Abundance	0.05058
Submerged Veg Abundance	0.04960

Salinity	0.03111
Reed Cover	0.02532
Supportive Substrate	0.02437
Access to Prey	0.02318
Depth to Submerged Vegetation	0.01602
Bathymetry	0.01539
Water Depth	0.01402
Height Submerged Vegetation	0.00192
Water Levels AHD	0.00151
Competition for Space	0.0008

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum***):***

- Salinity
- Connection to Mainland
- Water Depth (mean water depth at a site)

It is highly recommended that information is entered into the additional nodes to gain the best results (in order of importance):

- Height of Submerged Veg

Knowledge gaps

A number of knowledge gaps regarding Black Swan are apparent:

- This model requires more information regarding the impact of wave action on Black Swan nesting success.
- Black Swans are also known to forage on a few species of algae in the Murray Mouth estuary (e.g. Ulva, Enteromorpha, unidentified brown alga sp.). More information about the foraging behaviour of Black Swans, and the energetic implications of foraging on these species in the estuary is required to form a model that can be applied at this site.

Key Ecological Thresholds: Black Swan (freshwater)

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Submerged Vegetation cover	Expert Opinion	% cover	>70	20-70	<20	80%
Water depth (lake)	Expert Opinion	cm	50-75	20-50, 75-130	<20, >175	90%
Salinity*	Literature	ppt	0-10	10-20	>20	

*Impact on submerged and emergent veg abundance

Saline model:

Adult Survival is directly affected by: 1) Food availability

1. The main food source for Black Swans in the Coorong is the submerged vegetation species, *Ruppia tuberosa.* The abundance of *Ruppia* in the Coorong is determined by complex interactions, which cannot be captured in the current model. However, water depth was included as a predictor of *Ruppia* abundance, since there is a relatively simple (and strong) relationship between the two. Access to this food source is affected by the height of *Ruppia* plants in relation to overall lagoon water depth (therefore depth from the water surface to the top of the *Ruppia* plants). Black Swans reach their head down underwater to feed, and the length of their neck constrains whether they are able to reach food.

Figure 10 show forecasts for the Black Swan (saline) under "ideal" conditions of: water depth and height of submerged vegetation. Based on the probability distributions entered for "ideal conditions" (Figure 6), there is a 64% chance of high adult survival. Additional information can be entered into the model, which will update the probability of model outcomes.

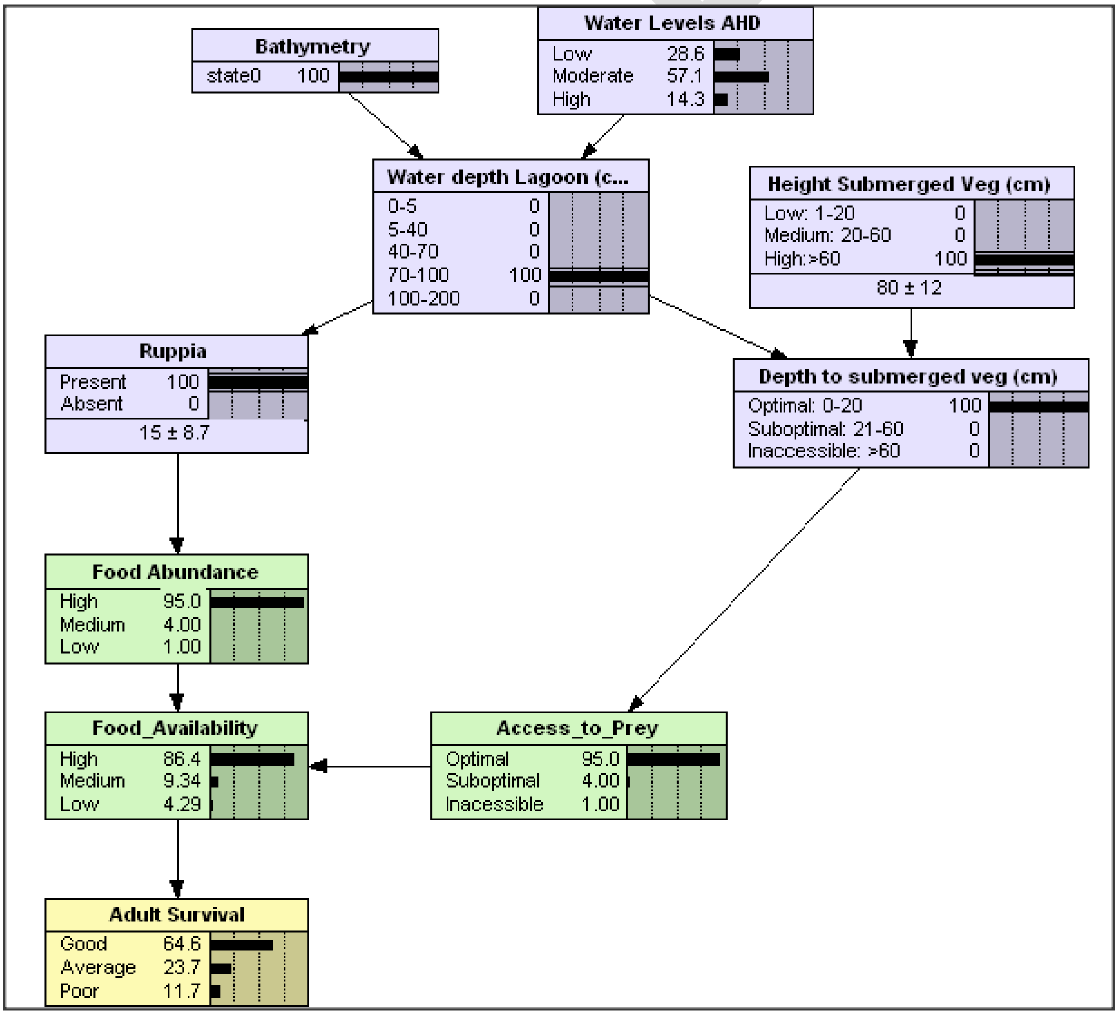


Figure 10. Black Swan (saline) model under 'ideal' conditions

Sensitivity Analyses

Table 9 shows that the nodes 'Food Availability', 'Food Abundance' and 'Ruppia' have the strongest influence on adult survival for the Black Swan. Information in these nodes or their immediate parents will therefore improve the model's ability to forecast overall swan energy intake. The following nodes are considered independent of the output node (Adult Survival), because they have no prior information in their conditional probability tables: 'Bathymetry', and 'Water Levels AHD'.

Table 9. Sensitivity of the 'Adult Survival' node to findings at other nodes in the Black Swan (saline) network. Variables are shown in descending order of influence.

Node	Mutual Information
Adult Survival	1.5617
Food Availability	0.24247
Food Abundance	0.14139
Ruppia	0.13933
Water Depth Lagoon	0.03717
Access to Prey	0.03027
Depth to Submerged Veg	0.02764
Height of Submerged Veg	0.00377
Bathymetry	0
Water Levels AHD	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum***):***

- Water Depth Lagoon (mean lagoon water depth at a site)

It is highly recommended that information is entered into the additional nodes to gain the best results (in order of importance):

- Ruppia
- Height Submerged Veg (cm)

Knowledge gaps

- The development of a Ruppia model would greatly improve the accuracy and information provided by the Black Swan (saline) model.

Key Ecological Thresholds: Black Swan (Saline)

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Water depth (lagoon)	Expert Opinion	cm	60	30-60, 60-100	<30, >100	95%
Ruppia abundance	Research required	% cores	High	Medium	Low/absent	

Chestnut Teal

Chestnut Teal (*Anas castanea*) are Australian residents that utilize Coorong habitats for non-breeding activities. ‘Adult Survival’ was identified as the major limiting factor that affects the persistence of this species at the site.

Adult Survival is directly affected by: 1) Food Availability, and 2) Access to Prey.

1. Food availability is a function of food abundance and access to prey. The preferred prey of Chestnut Teal in the Southern Coorong are *Ruppia* turions and Chironomids. Chestnut Teal are browsers that dabble in shallow water to forage for vegetative material and macroinvertebrates from the top of the sediment. Most foraging occurs within a few metres of the shoreline. Expert opinion indicates that *Ruppia* is the most important food source for Chestnut Teal in the Coorong, hence this food source has a higher weight on overall food abundance. Chestnut Teal are known to feed on brine shrimp when their preferred prey sources are not available (Bonner 2007). However, the availability of brine shrimp does not substantially increase the probability of adult survival for this species.

2. Access to prey is affected by water depth. Chestnut Teal forage by walking along substrate and ‘dabbling’ with their bills to capture food. These ducks are less likely to have high foraging performance if they are swimming in deeper water.

Figure 11 show forecasts for the Chestnut Teal under “ideal” conditions of: Salinity, water depth lagoon, and water depth (shore). Based on the probability distributions entered for “ideal conditions” (Figure 11), there is a 71.5% chance of high adult survival. Additional information can be entered into the model, which will update the probability of model outcomes.

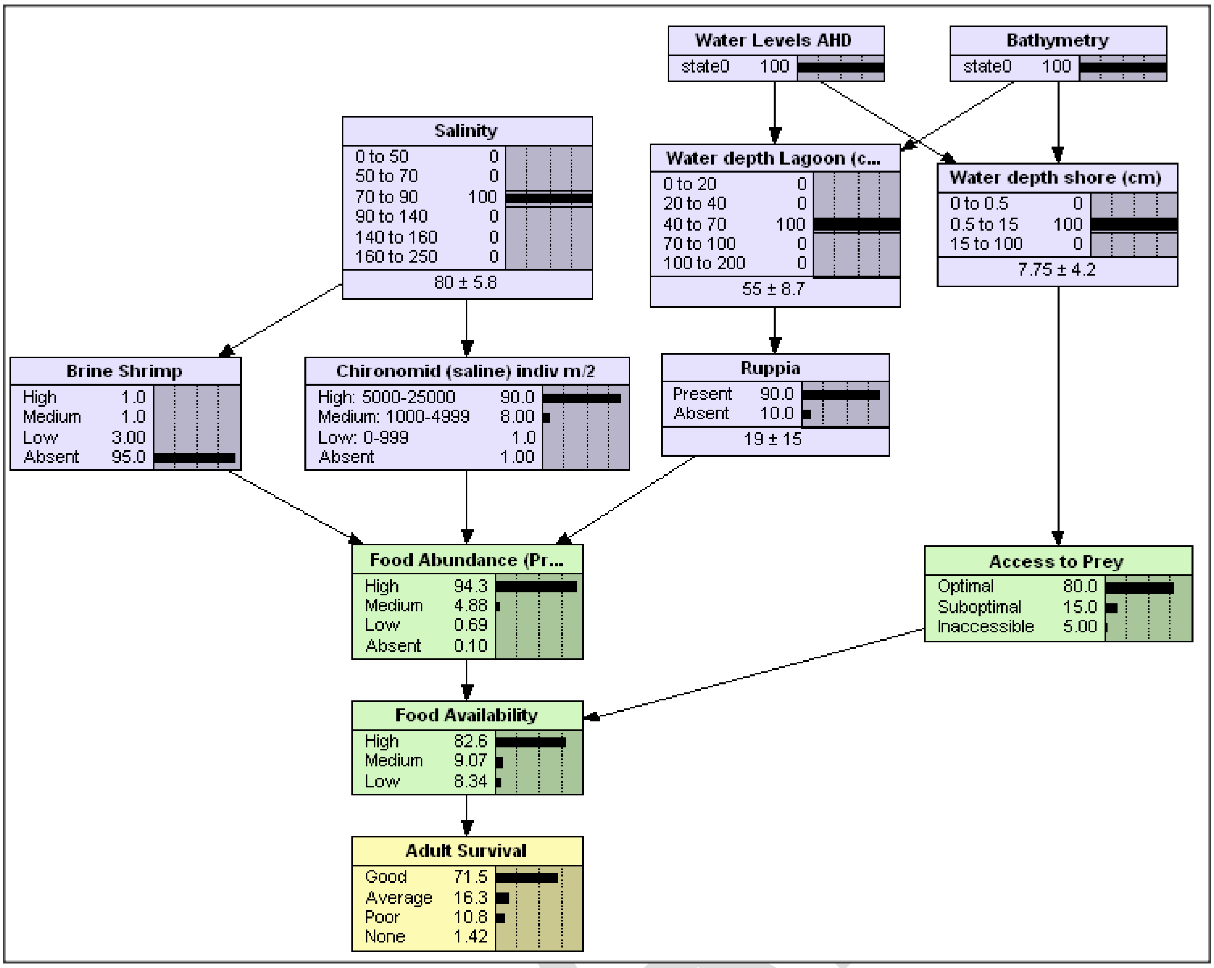


Figure 11. Chestnut Teal model under 'ideal' conditions

Sensitivity Analyses

Table 10 shows that the nodes 'Food Availability', 'Food Abundance' and 'Access to Prey' have the strongest influence on adult survival for the Chestnut Teal. Information in these nodes or their immediate parents will therefore improve the model's ability to forecast overall swan energy intake. The following nodes are considered independent of the output node (Adult Survival), because they have no prior information in their conditional probability tables: 'Bathymetry', and 'Water Levels AHD'.

Table 10. Sensitivity of the 'Adult Survival' node to findings at other nodes in the Chestnut Teal network. Variables are shown in descending order of influence.

Node	Mutual Information
Adult Survival	1.67464
Food Availability	0.43138
Food Abundance	0.13156
Access to Prey	0.11839
Water Depth (shoreline)	0.0639
Chironomid	0.05112
Salinity	0.03785

Ruppia	0.03387
Water Depth (Lagoon)	0.01764
Brine Shrimp	0.00265
Water levels AHD	0
Bathymetry	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum)***:***

- Salinity
- Water Depth Lagoon (mean lagoon water depth at a site)
- Water Depth Shore

It is highly recommended that information is entered into the additional nodes to gain the best results:

- Ruppia

Other considerations when applying the model

In the Coorong, Chestnut Teal historically foraged on both Ruppia and Lamprothamnium (submerged vegetation), as evidenced from gizzard and oesophagus contents from the late 1960s (Delroy 1974). Lamprothamnium is now virtually extinct within the Coorong (Paton 2010), and was therefore excluded from the models based on expert advice.

Chestnut Teal use Coorong habitats as 'drought refuge' when inland lakes are dry. Hence when inland lakes contain sufficient water, Chestnut Teal may leave the Coorong to breed; even if conditions in the Coorong are sufficient to support them. The BBN models for CLLMM do not incorporate conditions at other Australian wetlands, and should therefore be used with caution because Teal are likely to utilise breeding habitats outside of the Coorong at different times.

Knowledge gaps

A number of knowledge gaps regarding Chestnut Teal are apparent:

- The relative contribution of each food source to their diet is unknown. However, expert opinion indicates that overall food abundance may be high when there is a high abundance of Chironomids and/or *Ruppia*. To test the food preference of Chestnut Teal this model could be applied to the Morella Basin, where abundances of both Chironomids or Ruppia are usually high because of stable water levels (pers comm., D. Paton). This application could test the hypothesis that Ruppia is the preferred food item of Chestnut Teal, even when Chironomids are abundant. The alternative hypothesis being that Chironomids are the preferred food source for teal.

Key Ecological Thresholds: Chestnut Teal

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Water depth (lagoon)	Expert Opinion	cm	0.5-1.5	1.5-20	0, >20	80%
Ruppia abundance	Research required	% cores	High	Medium	Low/Absent	
Salinity*	Expert Opinion	ppt	70-90	50-70, 90-140	<50, >140	95%

*Impact on Chironomid (*Tanytarsus*) abundance

Results Part 5 - Reed-dependent Species

Purple Swamphen

The Purple Swamphen (*Porphyrio porphyrio*) is a reed-dependent species that predominantly uses freshwater habitats within the Lower Lakes. ‘Adult Survival’ and ‘Fledging Success’ were identified as the major limiting factors that affects the persistence of this species at the site. The quality of freshwater habitats for this species will broadly depend on conditions such as food availability and risk of predation. This model should be applied to freshwater (lakes) habitats only.

Adult Survival and Fledging Success are directly affected by: 1) Food Availability 2) Predation Risk. Fledging Success is also affected by 3) Nest Site Quality

1. Food Availability is affected by Food Abundance (three vegetation types) and Access to food. Purple swamphens usually feed on grass, reeds (new emergents), and submerged vegetation. Access to food is constrained by water depth above a given substrate (lower reed area or mudflat) and the proximity to thick vegetation cover (to hide from predators)

2. Predation risk is affected by the 5 cover of emergent vegetation cover, and the proximity of this cover for the bird. Swamphens require thick reedy vegetation to hide from predators. That vegetation also needs to be close to where they are foraging (so they can quickly run for cover). Predators may include terrestrial mammals such as foxes, cats and dogs, as well as avian predators such as large raptors.

3. Nest site quality is influenced by the availability of a supportive substrate, such as reed material (emergent vegetation) to construct and support nests and elevate them above wave action??.

Figure 12 show forecasts for the Purple Swamphen under “ideal” conditions of: Salinity, water depth to substrate, and proximity to cover. Based on the probability distributions entered for “ideal conditions” (Figure 6), there is a 67.6% chance of high adult survival and 55.8% chance of high fledging success. Additional information can be entered into the model, which will update the probability of model outcomes.

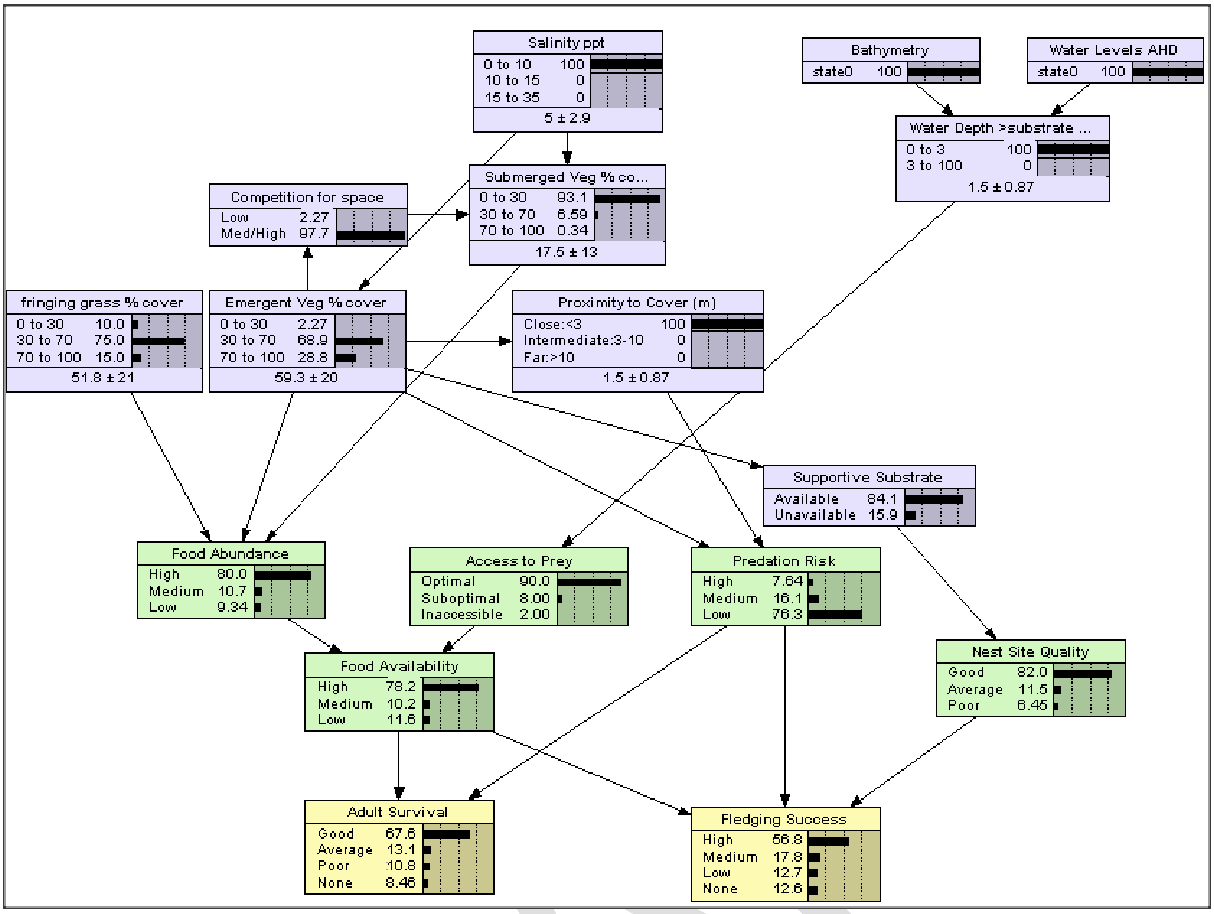


Figure 12. Purple Swamphen model under 'ideal' conditions

Sensitivity Analyses

Tables 11 and 12 show that the nodes 'Predation Risk, 'Food Availability' and 'Access to Prey' have the strongest influence on adult survival and fledging success for the Purple Swamphen. Information in these nodes or their immediate parents will therefore improve the model's ability to forecast overall swan energy intake. The following nodes are considered independent of the output node (Adult Survival), because they have no prior information in their conditional probability tables: 'Bathymetry', and 'Water Levels AHD'.

Table 11. Sensitivity of the 'Adult Survival' node to findings at other nodes in the Purple Swamphen network. Variables are shown in descending order of influence.

Node	Mutual Information
Adult Survival	1.62671
Predation Risk	0.12962
Food Availability	0.11057
Access to Prey	0.09063
Fledging Success	0.07308
Proximity to Cover	0.03052
Water Depth above substrate	0.02871
Emergent Veg % cover	0.01699
Competition for Space	0.01572
Salinity	0.00803
Food Abundance	0.00447
Fringing Grass % cover	0.00121
Submerged Veg % cover	0.00092
Supportive Substrate	0.00051
Nest Site Quality	0.00015
Water Levels AHD	0
Bathymetry	0

Table 12. Sensitivity of the 'Fledging Success' node to findings at other nodes in the Purple Swamphen network. Variables are shown in descending order of influence.

Node	Mutual Information
Fledging Success	1.66748
Food availability	0.09758
Access to Prey	0.07878
Predation Risk	0.07546
Adult Survival	0.07308
Water Depth	0.0263
Proximity to Cover	0.01528
Nest Site Quality	0.00764
Emergent Veg % Cover	0.00667
Competition for Space	0.00622
Food Abundance	0.00361
Salinity	0.00317
Supportive Substrate	0.00166
Fringing Grass % cover	0.00122
Submerged Veg % cover	0.00036
Water Levels AHD	0
Bathymetry	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum***):***

- Salinity
- Water Depth> substrate (water depth above substrate)

It is highly recommended that information is entered into the additional nodes to gain the best results (in order of importance):

- Fringing grass % cover
- Emergent veg % cover
- Submerged veg % cover

Other considerations when applying the model

The ‘Competition for Space’ node assumes that emergent vegetation establishes before submerged vegetation. If the opposite is true, then the relationship (direction of the arrow) will need to be reversed. For example, emergent vegetation, such as *Phragmites* or *Typha* reedbeds appear to be dominant species that establish quickly and can withstand a range of environmental conditions. Submerged vegetation such as *Vallisneria* or *Myriophyllum* species are more sensitive to environmental conditions and are less likely to be dominant before the establishment of reedbeds.

Knowledge gaps

A number of knowledge gaps regarding Purple Swamphen are apparent:

- This model would benefit from research into the impacts of vegetation cover and how this influences predation of nests.
- More information on Purple Swamphen diet is required. In particular, information on the proportions of each vegetation type that make up Purple Swamphen diet would improve the accuracy of the model.

Key Ecological Thresholds: Purple Swamphen

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Salinity*	Literature	ppt	0-10	10-15	>15	
Water Depth above substrate	Expert Opinion	cm	0-3		>3	90%

*impact on vegetation

Australian Spotted Crake

The Australian Spotted Crake (*Porzana fluminea*) is a reed-dependent species that predominantly uses freshwater habitats within the Lower Lakes. ‘Adult Survival’ was identified as the major limiting factor that affects the persistence of this species at the site. The quality of freshwater habitats for this species will broadly depend on conditions such as food availability and risk of predation.

Adult Survival is directly affected by: 1) energy intake 2) predation risk

1. Energy intake is affected by Food Availability (two veg prey types) and Access to Prey. Access to plant food (vegetation) is constrained by water depth above a given substrate (lower reed area or mudflat) and the proximity to thick vegetation cover (to hide from predators)

2. Predation risk is affected by emergent vegetation cover. Crakes require thick reedy vegetation to hide from predators, and vegetation also needs to be close to where they are foraging (so they can quickly run for cover).

Figure 13 show forecasts for the Australian Spotted Crake under "ideal" conditions of: Salinity and Water Depth. Based on the probability distributions entered for "ideal conditions" (Figure 13), there is a 58.5% chance of high adult survival and 76.1% chance of high energy intake. Additional information can be entered into the model, which will update the probability of model outcomes

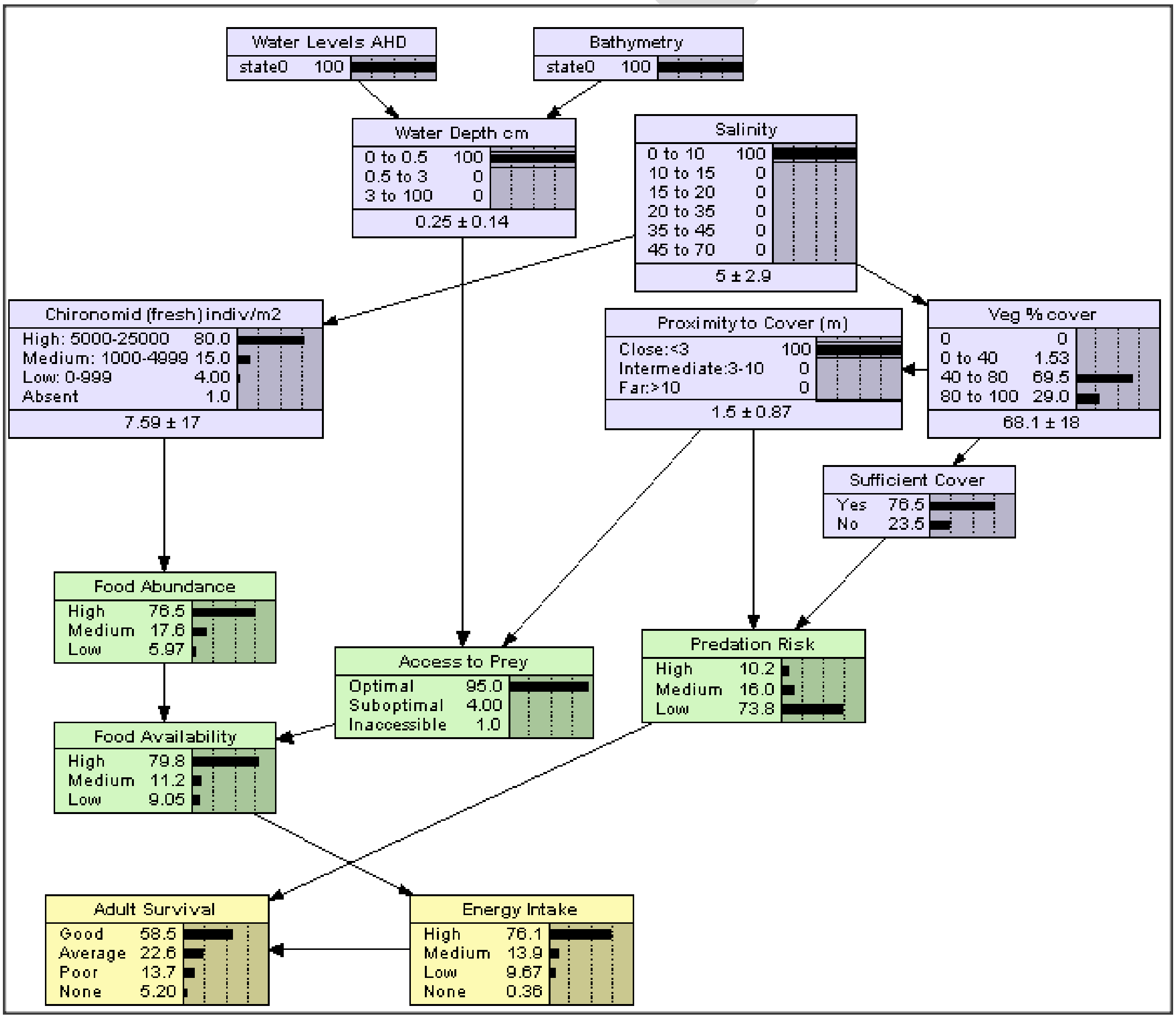


Figure 13. Australian Spotted Crake Model under 'ideal' conditions

Sensitivity Analyses

Tables 13 shows that the nodes ‘Energy Intake’, ‘Food Availability’ and ‘Access to Prey’ have the strongest influence on adult survival for the Australian Spotted Crake. Addition of information to these nodes or their immediate parents will therefore improve the model’s ability to forecast overall swan energy intake. The following nodes are considered independent of the output node (Adult Survival), because they have no prior information in their conditional probability tables: ‘Bathymetry’, and ‘Water Levels AHD’.

Table 13. Sensitivity of the ‘Adult Survival’ node to findings at other nodes in the Australian Spotted Crake network. Variables are shown in descending order of influence.

Node	Mutual Information
Adult Survival	1.96584
Energy Intake	0.53649
Food Availability	0.49904
Access to Prey	0.35734
Predation Risk	0.22358
Water Depth	0.16386
Proximity to cover	0.16361
Veg % cover	0.1009
Sufficient cover	0.09472
Food Abundance	0.0484
Chironomid	0.04335
Salinity	0.03659
Water Levels AHD	0
Bathymetry	0

Considering the results of sensitivity analyses and practicality of using available data, it is recommended that information should be input to the following nodes (as a minimum***):***

- Salinity
- Water Depth > substrate (water depth above substrate)

Knowledge **gaps**

A number of knowledge gaps regarding Australian Spotted Crake are apparent:

- More information about the diet preferences and habitat requirements of this species is required (but see O’Connor et al. in prep.)
- More information on the breeding status of this species in the CLLMM is required. It is likely that they breed in wetlands around the Lower Lakes, but there are very few records to support this.

Key Ecological Thresholds: Australian Spotted Crake

			Thresholds			
Indicator	**Knowledge**	**Unit**	**Ideal**	**Fair**	**Poor**	**Confidence**
Water Depth	Expert Opinion	cm	0-0.5	0.5-3	>3	95
Proximity to Cover	Expert Opinion	m	0-3	3-10	>10	90
Veg Cover	Expert Opinion	%	80-100	20-80	<20	65

General Results and Discussion

This project provides ecological models that assimilate current knowledge of CLLMM waterbird-habitat interactions. The Bayesian modelling approach allows for determination of the likelihood of habitat-suitability under different ecological conditions (see also Liedloff et al. 2009; O'Leary et al. 2009; Vilizzi et al. 2012). In doing so, these models provide a means of exploring how waterbirds potentially respond to different wetland conditions and how management of wetlands can influence the status of waterbird species representing important functional groups. The modelling approach can highlight the potential consequences of different sets of conditions possibly before changes in habitat suitability and population processes are immediately visible in the field.

Conceptual models

Conceptual models can form are an important component of the development and assessment of ecological monitoring programs (Lindenmayer and Likens 2009; Margoluis et al. 2009; Conroy and Peterson 2013). The conceptual models developed for this project provide a framework for understanding the ecological factors that affect waterbird habitats in the CLLMM. Specifically, these models identify habitat components that can be measured in order to forecast life-history outcomes for waterbirds at the site. These models have formalised our current understanding of wetland ecosystem dynamics and waterbird ecology. Moreover, the project highlights the diversity of information needed to forecast the suitability of CLLMM habitats for waterbirds.

Bayesian Belief Networks

Bayesian Belief Networks are probabilistic models that give graphical representations of the relationships between variables in a system (Nyberg et al. 2006; Korb and Nicholson 2010). They have been applied, tested and evaluated in the context of understanding species or ecosystem-level interactions in wetland systems (Pollino et al. 2007; Walshe and Massenbauer 2008; Vilizzi et al. 2012).

The eleven Bayesian Belief Networks models developed in this project provide a mechanistic understanding of the interactions between avian species and their wetland habitats. These network models provide important information for managers to make forecasts about the impacts of certain sets of ecological conditions on waterbirds. The models incorporate both expert knowledge and monitoring data to provide quantified measures of waterbird responses. The models present a series of hypotheses about waterbird life history in the CLLMM, and provide a systematic way to identify key knowledge gaps. In combination, this provides a framework for testing the models with new field monitoring data as it becomes available, and for targeting new research to build knowledge about ecosystem function. The models are also able to identify thresholds at which conditions positively or negatively affect waterbird success. For example, salinity levels may affect the abundance of multiple waterbird food resources, such as the four main prey groups identified for the Sharp-tailed Sandpiper. The optimal salinity for Sharp-tailed Sandpipers therefore reflects the salinity at which *overall* food abundance (incorporating all 4 prey groups) is high, which is different to the optimal salinity range for each individual prey group. In other cases, thresholds were derived directly from expert opinion or data (either raw data or in literature). For example, the optimal shoreline water depths for Common Greenshank foraging were identified as 0-6cm to access macroinvertebrates and 6-10cm to access fish. These thresholds were derived from expert opinion, but were also supported by monitoring data (Paton 2010, pg 150).

The BBN models developed in this project are intended to inform, and be informed by, other models such as macroinvertebrate, fish, vegetation, hydrology and bathymetry models. For example, 'mudflat' models are currently being developed for the Coorong (pers com J. Higham). These models will incorporate the relationship between bathymetry and water levels and will therefore be able to forecast the availability and location of mudflats in the Coorong. These models will enhance our ability to forecast suitable foraging areas for shorebirds such as the Sharp-tailed Sandpiper and Common Greenshank. A greater understanding of the relationships between Bathymetry and Water Levels (AHD) in particular will improve the ability of all waterbird models to forecast suitable habitat conditions. Hydrological models that quantify the relationships between other abiotic factors, water levels, and salinity can also be used as inputs into waterbird BBN models. This project did not aim to identify or quantify all of the factors that may affect variables such as salinity or water depth due to the complexity of those interactions (for example the link between salinity and water levels AHD is complex and involves other abiotic processes such as evaporation).

General Limitations and Assumptions

Food availability nodes (fish, vegetation, and macroinvertebrate) are intended to be linked to specific macroinvertebrate and aquatic vegetation models. For this reason, we do not attempt to define all of the factors that affect food availability within bird models. While some attempt was made to link waterbird success to key hydrological variables (particularly water level and salinity), these waterbird response models would be dramatically improved through the development of separate response models for key food resources (e.g. *Ruppia tuberosa*, macroinvertebrate, and Smallmouth Hardyhead response model). Furthermore, links between model components were not always included if they were too complex and required the inclusion of separate models (for example the link between water level and salinity, or salinity and some vegetation types).

Only three hydrological nodes: ‘salinity’, ‘water levels’, and ‘water depth’ are included with in the BBN models. Ultimately, the bird models should also be linked to more complex hydrological models that include important abiotic and biotic parameters (see Souter and Stead, 2010). We also lack information on key hydrological variables such as water levels (AHD) and fundamental physical features of the CLLMM such as bathymetry. All of these variables potentially impact on bird food availability and associated foraging behaviour.

Response of Waterbirds to Salinity of Aquatic Habitats

This project identified the main drivers and relationships that affect the life histories of 10 key waterbird species in the CLLMM. Importantly, each waterbird species relied on different components and sets of conditions within their preferred habitats. Salinity was a common component of 10 of the 11 waterbirds BBN models, and was only excluded from the Black Swan (saline) model due to very low levels of confidence in the relationship between salinity and submerged vegetation abundance (*Ruppia*). However, it should be noted that salinity is not the only factor impacting birds, and that other variables such as water levels are likely to be more directly related to waterbird habitat quality. Furthermore, the extensive inclusion of salinity in waterbird response models is largely based on the assumption that salinity is a primary driver of food abundance for all waterbird species. However, this assumption needs to be tested through the development of food species response models such that the importance of salinity can be placed in the context of other drivers of food availability.

Table 14. provide an overview of key salinity thresholds for waterbird species that are based on the ‘Key Ecological Thresholds’ developed during this project. The link between salinity and waterbirds is indirect; salinity has a direct impact on the physiology of waterbird food and habitat resources (macroinvertebrates, fish and aquatic vegetation), and thus only impacts waterbirds through its impact on the distribution and abundance of food and biotic habitat components. Salinity thresholds for waterbirds may therefore represent responses of various habitat components (species that provide food, nesting material, shelter) to variation in salinity. Waterbird species respond in different ways to the range of salinity conditions that are known to occur across Coorong habitats (see Lester et al. 2011; Higham 2012 for modelled salinity data). A salinity of 25ppt in the Coorong for example, may be ‘ideal’ for Common Greenshank, but ‘poor’ for Chestnut Teal (Table 14). This variation in preferred salinity highlights the importance of maintaining a diversity of hydrological conditions in the Coorong and Lower Lakes (Paton et al. 2009). In contrast, most species that utilise lakes

habitats respond positively to freshwater conditions (salinity<10ppt). These thresholds, along with the fish, macroinvertebrate and aquatic vegetation thresholds presented in Higham (2012), allow for direct analyses between hydrological characteristics (e.g. water flow and salinity) and ecological outcomes (e.g. success and/or abundance of flora and fauna species).

If the outcomes of the Murray-Darling Basin Plan (MDBA 2012) are achieved, maximum average daily salinity levels in the Coorong and Lakes will not exceed the salinity tolerance thresholds described in Table 14.

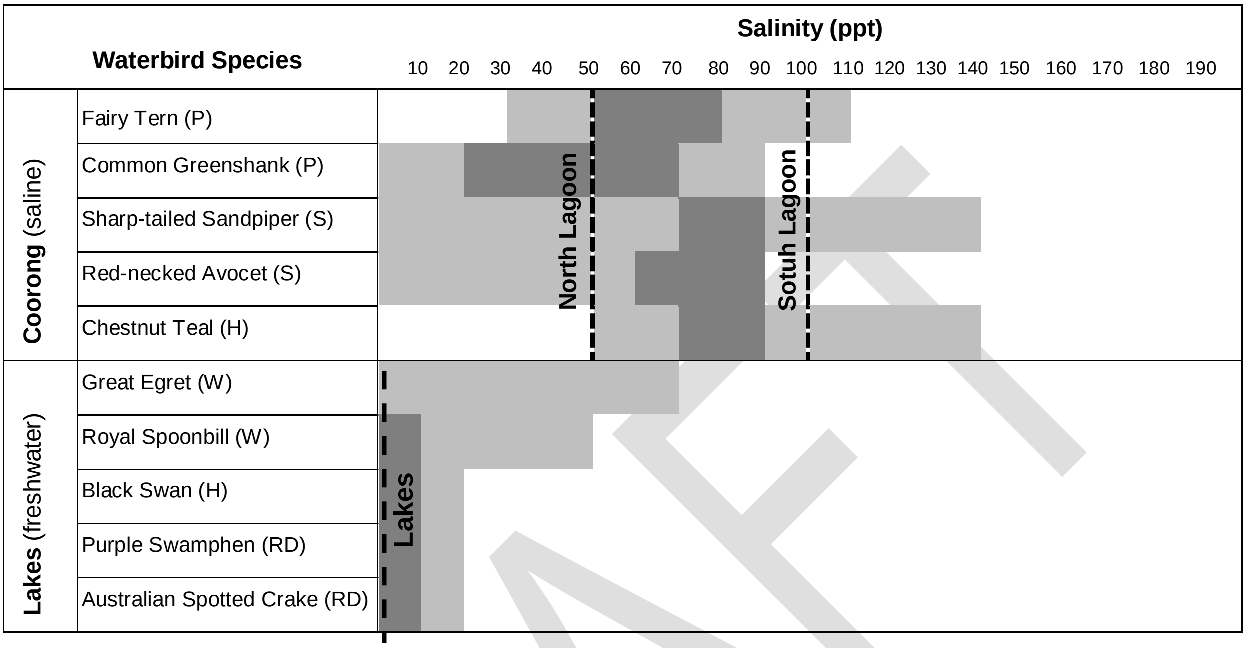
For example, the Basin Plan states that:

> *"The outcomes that will be pursued are:*
>
> *(a) further reducing salinity levels in the Coorong and Lower Lakes so that improved water quality contributes to the health of macroinvertebrates, fish and plants that form important parts of the food chain, for example:*
>
> *(i) maximum average daily salinity in the Coorong South Lagoon is less than 100 grams per litre; and*
>
> *(ii) maximum average daily salinity in the Coorong North Lagoon is less than 50 grams per litre; and*
>
> *(iii) average daily salinity in Lake Alexandrina is less than 1000EC for 95% of years and 1500EC all of the time; "*

Table 14 shows that the recommended maximum daily average salinity for the North Lagoon (50ppt) and South Lagoon (100ppt) allow for a range of salinity conditions across the Coorong. For each waterbird species, ‘Ideal’ salinity conditions fall below the maximums that are recommended for the North and South Lagoons. Similarly, the recommended maximum salinity of the lakes is <1ppt (using the conversion rate 1000EC= 0.64ppt), which is within the ‘ideal’ salinity ranges of all waterbird species that utilise lakes habitats (but ‘ideal’ ranges are unknown for the Great Egret). The recommendations provided within the Basin plan should therefore benefit a broad range of waterbird species.

The Key Ecological Thresholds provided in this report will contribute to the identification of broader Limits of Acceptable Change for CLLMM waterbirds, by identifying important and common factors that affect a range of different waterbird species. The ‘Poor’ thresholds can be considered within the context of developing LAC as they represent extreme minimum and maximum limits that are beyond the levels of natural variation. This information is intended to contribute to the Ecological Character Description of the site. The development of Key Ecological Thresholds instead identify ‘triggers’ at which management actions are required to ensure the persistence of quality waterbird habitats in the CLLMM.

Table 14. Salinity thresholds that indirectly affect waterbird species in the CLLMM. These thresholds are based on the "Key Ecological Thresholds' identified in this project. Salinity ranges represent physiological tolerances of waterbird prey or habitat resources (i.e. macroinvertebrates, fish and vegetation) and do not represent direct physiological thresholds for waterbirds. Dark grey shading indicate 'Ideal' ranges, light grey shading indicates 'Fair' ranges, and no shading represents 'Poor' ranges. Dashed lines represent maximum average daily salinity targets for the Coorong lagoons (North and South Lagoon), and the Lower Lakes (Lakes), as identified in the Basin Plan (MDBA 2012). Each species belongs to one of 5main functional groups: Piscivores (P), Shorebirds (S), Wading Birds (W), Herbivores (H) or Reed- Dependent (RD).



Response of Waterbirds to Local and Off-site Conditions

As with any model, the BBNs developed in this project are simplifications of real and complex ecological interactions. Most waterbirds that utilise the CLLMM site are mobile and many move outside of the region for parts of their lifecycle (Table 15). As a result CLLMM waterbirds are likely to be affected by a number of off-site factors that have not been fully addressed within this project, and are largely outside of the management scope of the region. These factors operate at a range of different spatial and temporal scales, and bird species responses to off site drivers are likely to be complex.

For example, migratory shorebirds that forage in CLLMM intertidal and shoreline habitats during the Austral Spring/Summer will migrate to international wetland sites for breeding (Table 15). The availability of food and nest sites at wetlands across the East-Asian Australasian Flyway may therefore impact the breeding success and physiological condition of these species before they attempt to migrate back to Australia to feed in the non-breeding season (Straw 2003; Paton 2010). Similarly, waterbirds that move between Australian wetland habitats (continental or regional nomads) may be affected by wetland conditions at regional or national scales (Kingsford and Porter 1993; Kingsford and Porter 2009; Brandis

2010; Murray et al. 2012). For example, overall population sizes of Australian Pelicans and Banded Stilt may be affected by flooding of inland salt lakes, which can trigger large-scale breeding events (Kingsford and Porter 1993). Other species, such as Chestnut Teal and the Australasian Bittern may move between wetlands at a regional scale (South-eastern South Australia) (Table 15). Overall population sizes and success of these species may be affected by the availability on regional wetlands for foraging, breeding and adult survival. Non-migratory species such as Fairy Terns and Hooded Plovers are considered 'residents', with little immigration or emigration between other Australian populations. Resident waterbirds will be affected by local CLLMM wetland conditions at all stages of their life cycles.

While an explicit term for external (off-site) impacts has not been included in the model where it is a factor, off-site drivers are worth considering in order to understand responses to local environmental change. This external influence is an important factor to consider across most waterbird species given their mobile nature.

Table 15. Major bird groups in the CLLMM grouped by migratory behaviour. Main drivers of population changes and example species are also provided.

Bird Group	Description of Group	Driver/s	Description of Main Driver/s	Example CLLMM species
Migratory Shorebirds	Birds that feed on intertidal mudflats of beaches, inlets, estuaries and sometimes inland wetlands. These birds migrate from the northern hemisphere to Australia during spring and summer.	1. **Local wetland features** (CLLMM) 2. **Off-site habitat availability** (Australian wetlands, staging areas of East-Asian Australasian Flyway, Arctic breeding areas)	1. **Local Scale**: Food abundance and access to food (Spring/Summer). 2. **National Scale**: food abundance and access to food (during Spring/Summer) at other Australian Wetlands (if CLLMM unsuitable). **International Scale**: Food abundance, access to food, nest-site availability/suitability at wetlands within the East-Asian Australasian Flyway (Autumn/Winter).	Sharp-tailed Sandpiper, Red-necked Stint, Curlew Sandpiper, Common Greenshank
Continental Nomads	Birds that migrate between Australian wetlands. Many species use the CLLMM as a 'drought refuge' during dry years but migrate to other Australian wetlands such as inland salt lakes to breed in large numbers (under wet conditions).	1. **Local wetland features** (CLLMM) 2. **Off-site habitat availability** (Australian wetlands)	1. **Local and National Scale**: Food abundance, access to food, nest-site availability/suitability.	Australian Pelican, Black Swan, Banded Stilt, Red-necked Avocet
Regional Nomads	Birds that migrate between the CLLMM and other South-Eastern South Australian wetlands.	1. **Local wetland features** (CLLMM) 2. **Off-site habitat availability** (South-East South Australian wetlands)	1. **Local and Regional Scale**: Food abundance, access to food, nest-site availability/suitability.	Australasian Bittern, Chestnut Teal
Residents	Non-migratory species that use CLLMM wetlands during all stages of their life-cycle.	1. **Local wetland features** (CLLMM)	1. **Local Scale**: Food abundance, access to food, nest-site availability/suitability.	Red-capped Plover, Hooded Plover, Fairy Tern

Confidence Levels and Application of Adaptive Management Principles

This project has identified the hypothesised relationships between birds and components of their habitats, while acknowledging the presence of knowledge gaps and uncertainties. Figure 14 outlines a proposed methodology for approaching components and relationships for which we have low or high confidence in available data/expert knowledge. Further research is recommended for situations of low confidence. For example, in the Sharp-tailed Sandpiper model, expert confidence around the relationship between macroalgal cover over sediment and macroinvertebrate abundance was relatively low (60%). Further research is required in order to increase confidence around this relationship. Conversely, in the Fairy Tern model, experts had high confidence (95%) in their estimates for the relationship between habitat inundation and nest site quality. When there is high confidence in available data or knowledge to support a model, hypotheses can be generated and tested in order to evaluate model predictions and outputs. This process may involve cycles of hypothesis testing and evaluation, where model assumptions are tested iteratively through appropriate application of management activity and monitoring the response of systems to this management.

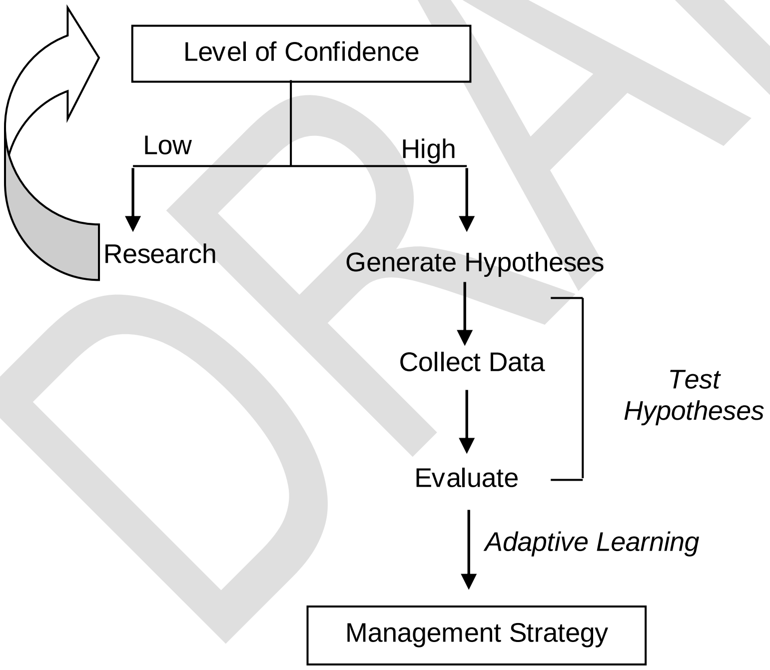


Figure 14. Conceptual diagram: the role of confidence levels and hypothesis testing in the application of waterbird BBN models to management.

Table 16 provides a process by which these BBN models can be applied within an Adaptive Management process (adapted from Nyberg et al. 2006). It is recommended that this process be followed in order to use waterbird BBNs to inform future adaptive management decisions in the CLLMM.

Table 16. Application of Bayesian Belief Networks to steps in the Adaptive Management process (Table adapted from (Nyberg et al. 2006))

Adaptive-management step	Application of Bayesian Belief Networks
1. Assess the problem	Graphically represent the structure of the system or parts of the system) to be managed. This structure may include: links between potential management actions, system components, and outcomes. Explore the effect of different scenarios (i.e. ecological) on model outcomes. Identify key knowledge gaps that require further research. Evaluate the sensitivity of forecasted outcomes to various inputs and alternative hypotheses. Document current understanding of system structure and relationships.
2. Design a management experiment	Select scenarios (or management actions) to be compared in the experiment by assessing sensitivities, knowledge gaps, and costs of implementation and monitoring. Formulate hypotheses for testing.
3. Implement the experiment	Use the BBN as a reference tool for managers to remain focused on key questions and management actions.
4. Monitor system responses	Compare monitoring results with outcomes that are forecast by the model to test whether monitoring effort is able to detect important effects. Use more sensitive indicators from the model or increase monitoring effort if required.
5. Evaluate outcomes and learn	Update conditional probabilities (in CP tables of BBN) using data from monitoring. Refine the model to incorporate reductions in uncertainties, the restructure the model to add system relations and components that were not previously recognised (or delete those that are unnecessary).
6. Adapt management strategies	Use the revised model to guide future decisions about management practices, including any future experiments and monitoring.

As suggested in the introduction, BBNs are a useful framework for the application of these adaptive management approaches. These steps will improve the ability of BBNs to make meaningful ecological forecasts, through the processes of testing, evaluating and refining their structure and conditional probabilities. The process also describes how BBN models can be used to inform monitoring and research of waterbird-habitat interactions in the CLLMM. The modelling approach developed in this study is intended to complement, and not replace, current field monitoring programs.

An important step in the testing and evaluation of these BBN models is to formulate and test hypotheses (Figure 14 and Table 16). Table 17 gives examples of hypotheses that could be explored in order to evaluate and apply the Sharp-tailed Sandpiper model. These, or similar hypotheses could be incorporated into monitoring objectives (when confidence in the relationship is high) or research programs (when confidence in the relationship is low). For example, the hypothesis that 'food accessibility decreases with increasing macroalgal cover over sediment' (low confidence) requires further research, whereas the hypothesis 'access to food is optimal when birds forage at a water depth of 0.1-2cm' (high confidence) should be tested and evaluated using monitoring programs.

Table 17. Example hypotheses for testing of the Sharp-tailed Sandpiper model.

Output	Contributing factors	Hypotheses	Confidence
Energy Intake	Access to food	**H1:** Food accessibility decreases with increasing macroalgal cover over sediment	**Low**
		H2: Access to food is optimal when birds forage at a water depth of 0.1-2cm.	**High**
	Food Abundance	**H1**: Sharp-tailed Sandpipers energy intake is 'high' when abundances of one of the following taxa are 'high': Chironomids (freshwater and saline species), Polychaetes, Amphipods or Ruppia.	**Low**
		H2: Sharp-tailed Sandpipers have equal preference for the food resources described in H1	**Low**
	Salinity	**H1**: Freshwater Chironomid abundance is 'High' at salinities of 0-10ppt	**High**
		H2: Saline Chironomid abundance is 'High' at salinities of 70-90ppt	**High**
		H3: Polychaete and Amphipod abundance is high at salinities of 30-40ppt when sediment sizes are between 125-250 µm	**High**

Conclusion and Recommendations

This project provides tools to guide the management of waterbirds species in the CLLMM through the development of conceptual and Bayesian models of avian habitat-use. These models can be used to forecast impacts of changing environmental conditions on habitat suitability at the site. Since these models incorporate expert knowledge of species responses to extreme ecological conditions (e.g. the 2002-2009 drought), they are likely to forecast realistic outcomes for a broad range of ecological conditions. The models can be used to test known ecological scenarios, or to simulate potential or forecasted scenarios at the site. Therefore, the development of models based on our current understanding of CLLMM processes and components may be a useful tool for learning what to expect and preparing to adapt to future ecological changes.

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Appendices

Appendix 1. Limiting Factors, Biotic and Abiotic factors used to construct conceptual models of avian habitat-requirements.

*this table attempts to translate conceptual model components into nodes within a Bayesian Belief Network. The “states” represent different ecological conditions, which will affect the probability given in the output node (the limiting factor).

Node	Template Category	Template Class	Description	States
Adult Survival	Limiting Factor	Adult Survival	A discrete node that describes the probability of adult survival.	**Adult Survival** Good Average Poor None
Energy Intake	Limiting Factor	Energy Intake	A discrete node that describes the energy intake/stores to be used for breeding/non-breeding activities. This node is a function of prey availability/access	**Energy Intake/Energy non-breeding** High Medium Low None
Fledging Success	Limiting Factor	Fledging Success	A discrete node that describes the probability of fledging success at the site	**Fledging Success** High (>60% nests) Medium (30-60% nests) Low (<30% nests) None
Access to prey	Driver	Access to Prey	A discrete node that describes the probability that prey will be accessible (for foraging).	**Access to Prey** **Access to Fish** **Access to Macroinvertebrates** Optimal Suboptimal Inacessible
Avian predation	Driver	Predation	A discrete node that describes the percentage of nests that are likely to be predated by avian predators (ravens, currawongs, seagulls, harriers).	**Avian predation**[,KG] Low (<20%) High (20-100%)
Bathymetry	Baseline Ecological Factor	Hydrology	A discrete node that describes topography.	**Bathymetry**[2] ?
Competition for Space	Baseline Ecological Factor	Vegetation	A discrete node that describes the “competition for space” between emergent and submerged vegetation.	**Competition for space** Low Med/high
Colony Size	Baseline Ecological Factor	Current Population Size	A discrete node that describes the colony size of Fairy Terns nesting at a site	**Colony Size** Large (40-80) Moderate (10-40) Small (1-10)
Connection to mainland	Baseline Ecological Factor	Hydrology	A discrete node that describes whether a nesting site is connected to the mainland (yes/no).	**Connection to mainland** Connected Not connected (island)
Current Population Size	Baseline Ecological Factor	Current Population Size	A discrete node that describes the the current population size of a waterbird species (based on most recent count data)	**Current pop size*** Large Moderate Small Category definitions will differ across species.
Depth to Submerged Vegetation	Baseline Ecological Factor	Hydrology/Vegetation	A discreet node that describes the depth between the water surface and maximum height of submerged vegetation.	**Depth to Submerged Veg (cm)** Optimal (0-20) Suboptimal (21-60) Inaccessible (>60)

Node	Template Category	Template Class	Description	States
Emergent Veg % Cover	Baseline Ecological Factor	Vegetation	A continuous node that describes the % cover of emergent veg (reeds and sedges) at a site	**Emergent Veg % Cover** State categories vary between models
Fish prey abundance	Baseline Ecological Factor	Prey	A discrete node that describes the abundance of fish (of a given size range) at a site	Fish <3cm Fish<12cm High (700-1200 CPUE) Medium (100-699 CPUE) Low (0-99 CPUE) CPUE= Catch Per Unit Effort
Fish caught per min	Driver	Food Availability	A continuous node that describes the probability of catching a certain number of fish per minute of foraging effort.	**Fish caught per min** **Fish caught per 5 min** values differ between species
Food abundance/ Food abundance (preferred prey)	Driver	Food Abundance	A discrete node that describes the abundance prey. Key prey species/body size are specified within each model (as separate biotic nodes).	**Food abundance** High (>60% of observed maximum) Medium (30-60% of observed maximum) Low (<30% of observed maximum) Absent
Food availability	Driver	Food Availability	A discrete node that describes the "availability" of food to a waterbird species according to prey abundance and access to prey.	**Food availability** High Medium Low
Fringing grass % cover	Baseline Ecological Factor	Vegetation	A continuous node that describes the % cover of "fringing" grass vegetation at a site	**Fringing grass % cover** 0 to 30 30 to 70 70 to 100
Habitat Inundation	Baseline Ecological Factor	Hydrology	A discrete node that describes whether a site has been inundated by water	**Habitat Inundation** Inundated Not inundated
Height Submerged Vegetation	Baseline Ecological Factor	Hydrology/Vegetation	A discrete node that describes the height of submerged vegetation (from sediment to maximum height of vegetation when in water)	**Height Submerged Veg (cm)** Low (1-20) Medium (20-60) High (>60)
Human/dog disturbance	Driver	Nest Site Quality	A discrete node that describes the risk of human/dog disturbance leading to nest abandonment/failure	**Human disturbance** Disturbed Undisturbed
Macroalgae % cover	Driver	Vegetation	A continuous node that describes the % cover of macroalgae over sediment at a site	**Macroalgae % Cover** 0 to 5 5 to 15 15 to 50 50 to 100
Macro-invertebrate prey abundance	Baseline Ecological Factor	Prey	A discrete node that describes the abundance of macro-invertebrate prey. Key prey species are specified within each model. *Linked to macroinvertebrate models*	**Macroinvertebrate prey abundance**[4,5] 1.Polychaete/Amphipod 2.Chironomid (saline) 3.Chironomid (freshwater) 4.Crabs <3cm 5.Snails 6.Brine Shrimp 7. Epibenthic Zooplankton High Medium Low Absent *values differ between species
Need for non-preferred Prey	Baseline Ecological Factor	Prey	A discrete node that describes the probability that the focal waterbird species needs to forage on non-	**Need for Non-preferred prey** Yes No

Node	Template Category	Template Class	Description	States
			preferred prey types. This node is heavily influenced by the availability of preferred prey	
Nest-site quality	Driver	Nest Site Quality	A discrete node that describes nest-site quality at a given habitat.	**Nest site quality** Low Medium High
Predation risk	Driver	Predation	A discrete node that describes the risk of predation.	**Predation Risk** High Medium Low
Predation	Driver	Predation	A discrete node that summarises the overall predation risk from multiple predators	**Predation** Yes No
Proximity to Cover	Baseline Ecological Factor	Vegetation	A continuous node that describes the distance between the waterbird/s and vegetation cover.	**Proximity to Cover (m)** 0 to 3 3 to 10 10 to 20
Proximity to Food Source	Baseline Ecological Factor	Prey/Hydrology	A continuous node that describes the distance between a suitable nest site and adequate prey resources.	**Proximity to Food (km)** 0-1km 1-2km >2km
Proximity to other colonial-nesting species	Driver	Behaviour	A discrete node that describes the distance to the nest site of another colonial-nesting bird species.	**Proximity Colonial Nesting** Close (<1km) Far (>1km)
Ruppia	Baseline Ecological Factor	Vegetation	A discrete node that describes the probability that *Ruppia* (submerged vegetation) is present or absent at a given site.	**Ruppia** Present Absent
Salinity*	Baseline Ecological Factor	Hydrology	A continuous node that describes water salinity. *Linked to hydrological models*	**Salinity** States vary across models according to salinity tolerances
Sediment grain size	Baseline Ecological Factor	Geology	A continuous node that describes the size of shoreline sediment grains.	**Sediment size, um**[5] 0 to 60 60 to 125 125 to 250 250 to 500 500 to 1000
Site suitable for occupation/site occupied	Driver	Nest Site Quality	Nest site is suitable for occupation or is already occupied	**Site suitable/occupied** Yes No
Submerged veg prey abundance	Baseline Ecological Factor	Vegetation	A discrete node that describes the percentage cover of submerged vegetation. Key plant species are specified within each model. *Linked to aquatic vegetation models*	**Submerged veg abundance**[,10] Low (<20%) Medium (21-69%) High (70-100%)
Sufficient Cover	Baseline Ecological Factor	Vegetation	A discrete factor that describes whether there is sufficient “cover” available to hide from predators. This node is a function of % emergent and terrestrial vegetation cover.	**Sufficient Cover** Yes No
Supportive Substrate	Baseline Ecological Factor	Vegetation	A discrete node that describes the probability that “supportive substrate” (i.e. reeds) is available (to be used as nesting material).	**Supportive Substrate** Available Unavailable
Terrestrial	Driver	Predation	A discrete node that describes the	**Terrestrial predation**[6,KG]

Node	Template Category	Template Class	Description	States
predation			percentage of nests that are likely to be predated by terrestrial predators (foxes, cats, dogs, snakes, ants).	Low (<10%) High (10-100%)
Terrestrial Veg % cover	Baseline Ecological Factor	Vegetation	A continuous node that describes the % cover of terrestrial vegetation (e.g. lignum and teatree) at a site	**Terrestrial Veg % Cover** State categories vary between models
Turbidity	Baseline Ecological Factor	Hydrology	A discrete node that describes the level of water turbidity (function of algal/suspended sediment density)	**Turbidity (NTU)** High >30 Medium 15-30 Low <15
Vegetation and rock cover	Baseline Ecological Factor	Vegetation/Geology	A discrete node that describes the heterogeneity of nesting substrate (veg and rock cover). Fairy Terns require sandy substrate to form scrapes, but require a certain level of protection from surrounding veg and rocks.	**Veg Rock Cover** Low Sufficient High
Veg Cover	Baseline Ecological Factor	Vegetation	A discrete node that uses information from other vegetation cover nodes to estimate overall vegetation cover (%)	**Veg Cover** High Low Absent
Water depth (cm)	Baseline Ecological Factor	Hydrology	A discrete node that describes water depth within a ecologically relevant microhabitat (for each species). *Linked to hydrological models*	**Water depth** **Water depth shore (cm)** **Water depth lagoon (cm)** Categories vary amongst models according to species-specific requirements (mainly beak size/leg length and therefore ability to access prey at different depths)
Water depth above substrate (cm)	Baseline Ecological Factor	Hydrology	A continuous node that describes the water depth above foraging substrate (mudflat or lower reedbed)	**Water depth > substrate (cm)** 0 to 3 3 to 100
Water levels	Baseline Ecological Factor	Hydrology	A discrete node that describes water levels (AHD) within an ecologically relevant microhabitat (for each species). *Linked to hydrological models*	**Water levels** ?

Data sourced from/to be sourced from: [1] CLLMM fish ecology models (in development), [2] CLLMM GIS maps, [3] Lester et al. 2011, [4] Macroinvertebrate ecology models (Ecological Associates), [5] Sabine Dittman's lab- Flinders University, [6] Fairy Tern Survey, [7] Expert opinion-David Paton, Adelaide University, [8] CLLMM fish ecology models (in development), [9] *Ruppia* surveys, David Paton, Adelaide University, [10] Submerged vegetation ecology models (in development), [11] Paton 2010, [12] Rogers and Paton 2009, [13] HANZAAB, [14] Environmental Protection Authority, [KG] indicates Knowledge Gap

Appendix 2. Expert profile form

This form is used to gain a profile of the previous knowledge and expertise of workshop participants (adapted from Murray, 2009 and Fisher et al. 2012), and is a standard component within expert elicitation protocols. This information will be used to give a general overview of collective expert knowledge in the methods section of corresponding reports. We will not indicate the individual experience/qualifications of any participant within reports/publications. Any information that you provide here is confidential and will not be shown to other participants or used to rank your input.

Name:……………………………………………………………………Date:………………………………

Describe level of expertise in bird ecology (ie qualifications, experience, part of your current job?)

………

………

………

How was the expertise gained? (indicate all applicable):

- ☐ - field work
- ☐ - literature
- ☐ - other (please state)……………………………………………………………………………………

………..

Was expertise gained by (indicate all applicable):

- ☐ - solo work
- ☐ - group work
- ☐ - as supervisor
- ☐ - supervised
- ☐ - other (please state)…………………………………………………………………………………

Over what time frame was your expertise gained? (tick appropriate answer):

- ☐ - < 12 months ago
- ☐ - 1-5 years ago
- ☐ - 5-10 years ago
- ☐ - >10 years

How do you rate your statistical knowledge? (indicate all applicable):
*We do not expect you to have statistical knowledge to participate in this workshop

- ☐ - Non-existent
- ☐ - Last covered at school
- ☐ - Undergraduate-level or beginner courses
- ☐ - Postgraduate-level or advanced courses
- ☐ - Continual exposure through reports/literature
- ☐ - Regular use and some understanding
- ☐ - Advanced usage, modelling and understanding

Appendix 3. *Scenario Testing*

Red-necked Avocet Abundance in relation to Chironomid and fish abundance

Adelaide University (Paton) bird data					**Macroinvertebrate Data (Dittman) {Keuning, 2011 #87}**			**SARDI fish data (Yi)**		**Anecdotal**
Year	**site code**	**Easting**	**Northing**	**# Birds**	**site code**	**location**	**Chironomid abundance mean indiv m2**	**Fish site**	**Hardyhead**	**Brine Shrimp**
2009	5	353781	6029364	445	24	Parnka Point	<500	Hells gate	1.8	High
2009	33	346133	6035086	597	24/26	10km south of noonameena	<500	Noonameena/Hells Gate	248	High
2009	61	340734	6043659	417	NM/26	Noonameena	<500	Noonameena	248	High
2009	220	364396	6020777	616	PaP/VdY	6km south of point 19, 8km north of point 16	<500	Hells gate/Jack's Point	0.15	High
2011	241	368699	6014958	1023	16	Fat Cattle Point	11000	Jack Point	38	Low
2011	244	369500	6014244	412	16	Fat Cattle Point	11000	Jack Point	38	Low
2011	245	368127	6013529	557	16	Fat Cattle Point	11000	Jack Point	38	Low
2011	254	369735	6011025	420	16	Fat Cattle Point	11000	Jack Point	38	Low
2011	275	373057	6005056	606	14/16	halfway between 14-16, 8km from ea	500-10000	Jack Point/Salt Creek	103.2	Low
2011	298	377365	5998402	419	14	Sandspit	1000	Salt Creek	168.1	Low
2012	58	341164	6042744	583	NM	Noonameena	3000	Noonameena	1044	Low
2012	60	339443	6041615	1030	NM	Noonameena	3000	Noonameena	1044	Low
2012	223	365054	6019976	1261	PaP/VdY	6km south of point 19, 8km north of point 16	<500	Hells gate/Jack's Point	972	Low
2012	226	365826	6019362	482	PaP/VdY	6km south of point 19, 8km north of point 16	<500	Hells gate/Jack's Point	972	Low