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Dealing with uncertainty: an innovative method to address climate change adaptation in the whale watch industry

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Abstract: Impacts of climate change on natural and human 'systems' are often difficult to assess due to high uncertainty and the need to integrate trans-disciplinary knowledge. This includes the worldwide, billion-dollar whale watching industry that depends on some key species such as the humpback whale. The migratory corridors, feeding, resting and calving sites, which are used for whale watching may be influenced by changing ocean currents and water temperatures. Whales are responding through a shift in migration time, behavior, abundance and distribution impacting on whale watching. To address these challenges, the authors developed a participatory model to understand and evaluate the potential effects of climate change (and other determinants) on the whale watching industry using the east coast of Australia as a case study. Using systems thinking and engaging with participants from the whale watching industry, a system structure for whale watching was developed. Elements encompassing climate change (e.g. length of season, temperature), policy (e.g. number of boats), ecology (e.g. number of whales age structure) and socioeconomics (e.g. number of tourists, fuel price) were integrated into this model with the interdependencies and feedback pathways investigated. Using the systems thinking model to help the participants contextualise and visualise their whale watching system, a Bayesian network (BN) model focusing on the determinants of 'Whale Watching Profitability' was then developed. The participants defined the structure and conditional probabilities for the BN. A sensitivity analysis on the BN helped identify important intervention points for the industry. This innovative methodology can be applied to other fields and can assist businesses and authorities in making rational management decisions even when data is very limited.

***Keywords**:* climate change adaptation; whale watching; systems thinking; Bayesian network models; participatory modelling; Australia

1 INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) are a popular whale watching species that undertake their migrations in concert with seasonal shifts and environmental triggers. There is growing concern that humpback whale migrations are influenced by climate change with shifts in major currents such as the East Australian Current (EAC) being linked to dramatic effects both on the physical and biological marine environment (Corkeron and Connor, 1999; Hobday, 2006; Loeb and Santora, 2015). Recently it has been shown that, over a 27 year observation period in the North Atlantic, humpback whales had arrived at their summer feeding ground on average one day earlier every year compared to the previous year. The reason for this change in arrival time was linked to a response to increasingly warmer waters (Ramp et al., 2015).

Key stakeholders operating within the whale watching industry (e.g. operators, regulators) require an improved understanding of how changing climate will affect humpback whale migration patterns. However, a core challenge is that whale watching industry is a complex system involving socio-ecological interactions and characterised by multiple feedbacks, interdependencies, and chaotic and discontinuous non-linear relations of their elements (Patten and Jørgensen, 1995, Lambert et al., 2010). Furthermore, the 'elements' of this system range across multiple disciplines (e.g. physical, biological, social, economics, governance). Finally, there is great uncertainty in this information underpinning the system.

To help the whale watching industry manage the effects of climate change, an integrated approach is needed to address the complexity, uncertainty and dynamic nature of this problem. This project combines and applies two methodologies, (i) Systems thinking and (ii) Bayesian network modelling to address these fundamental issues.

Systems thinking provides a mechanism for integrating analytic and synthetic methods, encompassing both holism and reductionism. It was first proposed under the name of "General System Theory" by the biologist (von Bertalanffy, 1950) and involves:

- Building analytical models explaining system behaviour,
- Developing a set of strategies that combine observations with the use of models and informed judgments,
- Comparing the alternative strategies
- Using the results to inform decision process by interacting with decision-makers,
- Making decisions based on the information obtained, and
- Monitoring and evaluating the results of the decision implemented.

Bayesian network (BN) modeling is a probabilistic-based methodology that uses directed acyclic graphs (DAG). It is well-suited to representing causal relationships between variables in the context of variability, uncertainty and subjectivity, even when data is sparse or disparate (Nadkarni and Shenoy, 2004). Much of their utility arises from their ability to integrate data (knowledge) across multiple- and trans-disciplinary areas, especially where data is sourced through 'expert opinion' (Kjærulff and Madsen, 2008).

In this project we aimed to develop and use stakeholder-driven systems thinking and BN models to assess the impacts of climate change on the whale watching industry. Specifically, we developed these participatory models to help explore climate change adaptation and adaptive capacity for the whale watching industry in south-east Queensland, Australia.

2 METHODS

2.1 Systems diagram

Central to systems thinking is a systems diagram (Loucks et al., 2005) that contains a series of elements (variables) interconnected by links. These interconnections between variables indicate (1) causality (showing the cause and effect relationship) and (2) polarity (positive / negative) showing the direction in change between the two variables. A feature of systems diagram are feedback pathways, which can be (i) reinforcing (promotes change) and/or (ii) balancing (suppresses change) loops. It is the combinations of these reinforcing and balancing loops that provides insightful information about how the 'system' operates i.e. linking system structure to system behavior.

Prior to engaging with the key stakeholders, a general systems diagram for the south-east Queensland whale watching industry was developed by the researchers (the co-authors of this paper). The purpose of this was to provide a starting point for discussion about the potential consequences of climate change on the whale watching industry at a stakeholder workshop. The general systems diagram was developed using peer-review literature and the expert knowledge of the authors of this paper. Broad thematic areas (sectors) associated with the whale watching industry and climate change (e.g. governance, biological, physical environment, economic) were first identified. Variables within these sectors (e.g. water temperature) and the causal links between them were then elicited. This created sector-specific systems diagrams. These sector-specific diagrams were then linked creating an industry-level general systems diagram. This diagram was then presented to stakeholders from the whale watching industry at a workshop held at the Gold Coast (Australia) in December, 2014. The general systems diagram was presented at the workshop and feedback elicited from the participants (comments, clarification and recommended changes). This resulted in a final systems diagram for the industry.

2.2 Bayesian network model development

BN modelling was used to coalesce the understanding and perceptions of the workshop participants around the issue of potential climate change impacts on the south-east Queensland whale watching industry. The development of the model structure and the assigning of the conditional probabilities used to parameterize the model were based on 'expert opinion'. Both components (model structure and parameterization) occurred during the workshop.

The development process for the BN started with the workshop participants selecting a 'priority issue' for further assessment. This priority issue was based on discussion amongst the group regarding an important management aspect associated with the whale watching industry in the context of their systems diagram.

The participants were then presented with the fundamental steps of developing this BN including providing information on standard BN terminology (i.e. *variables*, *nodes*, *states* and *conditional dependence*). They were shown how their priority issue became the starting point of the BN construction process by getting them to discretise it with two states; a *desirable* state and an *undesirable* state. This process transformed the selected priority issue into a variable. The participants were also provided with information regarding the 'rules' governing the discretisation of BN variables, specifically the states must address all possible outcomes, be mutually exclusive and be consistent for that variable (Uusitalo, 2007). It is also highlighted that these states should be broad and qualitative.

Given this background information on constructing the structure of a BN, the participants were then provided with the following prompting statement:

"Identify the variables that directly influence your capacity to manage the priority issue"

The participants were instructed to select a maximum of three parent nodes (termed here as primary-level variables) and to discretise these with a maximum of two states ('desirable' and 'undesirable' states). They were also instructed to make these primary variables independent from one another so that the states of one of these were not influenced by, or have influence on, another. A follow-up statement was then provided that emphasised direct causality:

"Identify the variables that directly influence these primary-level variables"

Again the participants were instructed to assign two states to these *secondary variables* using the same guiding rules as for the primary-level variables. However, it was also stated that there might be instances where it would be more informative to assign states that do not necessarily reflect a desirable and undesirable state but rather reflect the two possibilities (e.g. small area / large area).

The rationale for limiting the number of states to two for all of the variables is that it makes the associated conditional probability tables (CPTs), which are populated using expert elicitation of the participants' knowledge, more tractable. The participants were informed at this stage of BN development that restricting the maximum number of parent nodes per child node to three and the number of states per node to two were pragmatic decisions related to being able to develop the model. However, information on CPTs was purposefully withheld from them at this stage to avoid this influencing the selection of parent nodes (i.e. the participants might reduce or limit the number of parent nodes influencing a child node as a means of reducing complexity of the associated CPT).

Depending on time availability during the workshop, the participants were advised that an additional level of nodes (tertiary-level nodes) could be added to the BN using the second prompting statement.

The result of this process was the development of a directed acyclic graph (DAG) (Figure 1) characterised by two to three hierarchical levels above the focus variable.

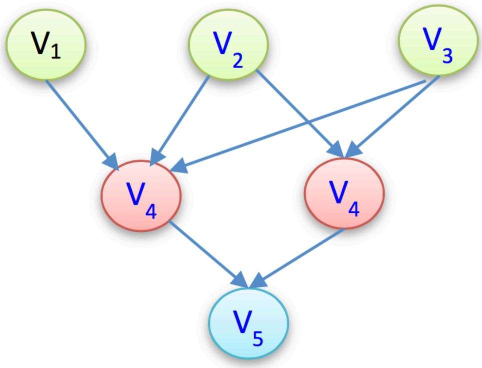

Figure 1. Example of a directed acyclic graph as created for BNs. The bottom variable (V5) represents the priority issue with which the BN is built around during the workshop.

As shown in Figure 1, The DAG consists of nodes and directed links: Nodes represent variables of interest while the directed links represent statistical or causal dependencies among the variables. The final stage of developing this BN was populating the associated CPTs. The conditional probability distributions were quantified for each node given its parents in the graph. The utility of BNs is dependent on assigning conditional probabilities to the tables that underpin the dependent nodes within the model. This can be a difficult process when using expert opinion, especially when there are a number of parent nodes involved and/or the nodes involved have a high number of discretized states (Richards et al., 2013). It is common to use 'pen and paper' or spreadsheets (Heuer, 1999) to generate these conditional probabilities. In this research, we use an iPad application (app) called App2Adapt, which has been deployed successfully in previous research projects (Richards et al., 2014). This app uses interactive sliders to represent conditional probabilities i.e. participants slide the slider button along a range that represents 0 – 100% for each of the conditional relationships that need parameterizing.

Contrasting the development of the BN structure, which was based on the collective belief of workshop participants, the CPTs were populated based on individual participant beliefs. We obtained this data through the participants assigning percentages to the CPTs that represented their belief in the strength of these relationships. Finally, we used Netica software (Norsys Software Corp., v. 5.12) to develop and test the BN model.

3 RESULTS AND DISCUSSION

3.1 Conceptual model based on systems thinking approach

The developed conceptual model was based on the expert knowledge of the authors of this paper, peer-reviewed literature and contribution from 11 participants at a stakeholder workshop. It provides a cognitive mapped model of the whale watching system for the Gold Coast area, Australia and was designed to provide an improved understanding of the sensitivities of the variables (i.e. leverage variables, determinants of these leverage variables) to climatic and non-climatic drivers.

Four modules were identified for the general systems diagram: climate change, biological, economic and management modules (Figure 2). The main drivers in the climate module included water temperature and wind (speed) and in the biological module it was migration time, stock quantity and krill/fish (food supply). The main variables in the management module were regulations, enforcement (monitoring, compliance) and education (PR). The main economic drivers were number of tourists and income. The model took into account the reinforcing and balancing loops between variables. For example the climate change variable "water temperature "influences "whale behavior", which influences the whale watch tourism variable "distance from shore" and then influences "tourist numbers". But "tourist numbers" are also directly influenced by "water temperature".

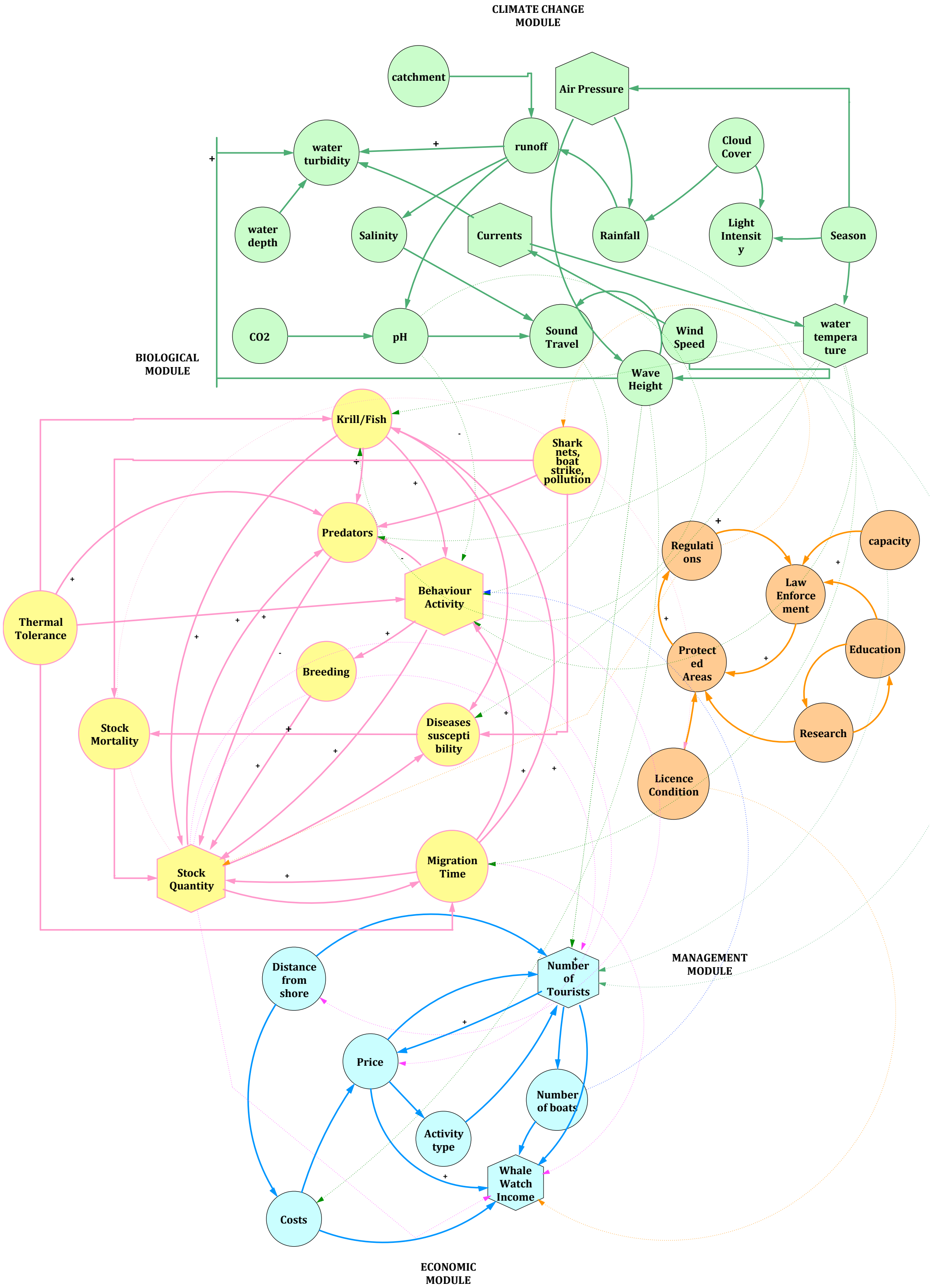

Figure 2. Conceptual model discussed with stakeholder. Hexagons indicate important variables (based on Meynecke et al., 2015).

3.2 Bayesian Network

The workshop participants selected the priority management issue “Profitability” as their focal point for developing a BN. It was discussed amongst the participants that this included the element of perceptions/expectations of customers (i.e. not just economic profitability). The primary level nodes (those that are directly linked to the priority issue node) selected by the participants were “Customers”, “Costs” and “Whales”. The meaning of these nodes were discussed at length and were defined (short definitions) as:

- “Customers”- related to expectation of the whale watchers,
- “Costs”- included fixed and variable costs such as boat maintenance, staff and marketing; and
- “Whales”–included healthy population of whales with natural behaviour in proximity to shore to allow for whale watching.

Nine secondary level nodes for the BN were identified by the workshop participants (Table 1).

The workshop participants then parameterized this BN using the iPad app (App2Adapt) to assign the underlying conditional probabilities. An auxiliary node was included within the BN so that the ‘stakeholder effect’ on the conditional probabilities could be assessed. A sensitivity analysis on the parameterized BN (focusing on the priority node ‘Profitability’) showed that the three primary-level nodes had the greatest influence on “Profitability”. Of these primary nodes, “Customers” was the most influential (on “Profitability”), followed by “Whales” (i.e. whether they are available or unavailable for whale watching) and then “Costs”.

Table 1. Secondary-level nodes and definitions as selected by the workshop participants

Node name	**Definition**
Weather	improve ability to get the customers to the whales e.g. larger vessel, covered deck
Marketing	influencing perceptions/expectation of the customers in selling the product
Competition	over time and with other whale watch operators
Fuel	cost of fuel to travel to whales
Wages	cost of wages for staff (skipper, deckhand etc.)
Assets	cost of maintaining and acquiring assets (boats)
Weather	better protection for customer from weather
Timing	timing when whales occur
East Australian Current (EAC)	the impact of EAC on whales

4 CONCLUSIONS AND RECOMMENDATIONS

In this project we combined two participatory methods to establish a first concept and issue a management target under climate change for a regional whale watch industry. This approach is applicable to other whale watching regions around the world. Using two modelling techniques (systems thinking and Bayesian Network modelling) we synthesised available knowledge from experts, literature and stakeholders across different disciplines to understand the structure of the whale watching industry and how this might influence future behavior under climate change. Furthermore, the participatory modelling process helped the whale watching industry participants to contribute to furthering our understanding of the problem (climate change impacts on the whale watching industry). They did this by engaging with the researchers to build a consensus understanding of the ‘system’, helping to identify both challenges and opportunities for the whale watching industry and providing a forum for discussion between industry practitioners and decision makers. Outcomes from similar projects in natural resource management have been promising (Bosch et al., 2007). However, the approach also requires well-managed and planned collaboration and co-production throughout the knowledge creation, synthesis and application process (Van de Ven, 2007) and willingness to invest considerable time and resources to develop the model (Best and Holmes, 2010). Often outcomes can be limited by the number of available stakeholders and the influence of a few individuals on the process. It may be necessary to reach out to stakeholders through social media, e-mail and phone and the reimbursement of costs to attend the workshop should be considered to encourage participation.

This field of research has currently very little data to predict the scale of change and the first studies demonstrating response of humpback whales to climate change are just emerging (Ramp et al., 2015). Future studies would greatly benefit from whale migration models under different climate change scenarios and further research into the biological and socio-economic extend of climate driven variables.

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