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ORIGINAL ARTICLE

# Whale watch or no watch: the Australian whale watching tourism industry and climate change

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**Abstract** Whale watching is a billion dollar industry worldwide. One of the most popular species for whale watching is the humpback whale (*Megaptera novaeangliae*). The migratory corridors, feeding, resting and calving sites which are used for whale watching may be influenced by changing ocean currents and water temperatures. Here, we used an innovative approach addressing the emerging issue of climate change on the whale watch industry. This involved participatory modelling using key stakeholders for the whale watching industry to develop a systems conceptualisation model for evaluating the potential effects of climate change based on a case study from the east coast of Australia. This participatory approach allowed us to identify the causal linkages (including feedback pathways) between different "Elements" of the system within which the whale watching industry operates. It also allowed us to integrate multiple drivers covering socio-economic and environmental aspects including climate change (e.g. temperature), policy (e.g. number of boats), ecology (e.g. number of whales) and socio-economics (e.g. number of tourists) to evaluate the changes in the overall system. We then developed a Bayesian belief network model from the systems conceptualisation on which stakeholders identified a priority issue (Profitability). Stakeholders provided the structure and the quantification of this model, and a sensitivity analysis was carried out to help identify important intervention points for the industry. Overall, our research illustrates how such a modelling process can assist local tourism operators and authorities in making rational management decisions within a holistic or systems-based framework and its approach is applicable to other regions.

**Keywords** Whale watching · Climate change · Adaptation · Stakeholder · Bayesian belief network

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## Introduction

Whale watching is a major global tourism industry with an annual revenue of over two billion (US dollars) and more than 13,000 employees worldwide (Cisneros-Montemayor et al. 2010). Furthermore, it is estimated that close to 15 million people every year participate in whale watching (Hoyt 2001; Knowles and Campbell 2011; Cunningham et al. 2012).

Whale watching is an important industry on the east coast of Australia, particularly for the Gold Coast in south-east Queensland where five whale watch operators with a daily carrying capacity of 1000 customers. After whale hunting ceased in the late 1960s, some whale species such as humpback whales began to recover and their numbers increased annually by up to 10 % (Noad et al. 2011). The growth of this industry is mainly attributed to the recovery of well-known whale species and the concomitant increase in their density (Jackson et al. 2006; Noad et al. 2011), which has prompted many operators to now offer a money-back guarantee if there are no sightings (A. Ardern *pers. comm.*).

Popular Gold Coast whale watching species like humpback whales (*Megaptera novaeangliae*) undertake their migrations in concert with seasonal shifts and environmental triggers. Most notably, ocean currents have been linked as a major determinant for these migrations (Corkeron and Connor 1999). Other shifts in migration may occur due to changes of Antarctic krill abundance and distribution (Loeb and Santora 2015), which is the main food source for the southern Hemisphere humpback whale populations. Recent and projected shifts in the East Australian Current (EAC) are linked to dramatic effects both on the physical and on biological marine environment (Poloczanska et al. 2007; Bindoff et al. 2007), which could influence the whale migration dynamics with associated impacts on the local (Gold Coast) whale watching industry. Evidence of this impacting on the whale watching industry may have already been observed in Hervey Bay, Queensland, Australia, where an increase in water temperature in 2014 was attributed to causing the early (2 weeks) closure of the whale watching season due to low numbers of whales (P. Lynch *pers. comm.*). This supports evidence from a recent North Atlantic study that demonstrated that humpback whales arrived on average 1 day earlier every year compared to the previous year at their summer feeding ground over a 27-year observation period (Ramp et al. 2015).

Expansion of the annual "Whale watch season" by up to 2 weeks along the Gold Coast in May (J.-O. Meynecke *pers. comm.*) and the use of habitats that were previously not frequently occupied (Vang 2002; Smith et al. 2012) suggest that climate change might not only have adverse impacts but also create opportunities for the whale watch industry.

An improved systems-based understanding of whale watching linked directly and indirectly to climate change is needed in order to adapt current natural resource management practices for future conditions. Building adaptive capacity refers to the potential capability, or ability of the whale watch industry to adapt to climate change.

A systems-based approach to natural resource management recognises a need to account for the complex and highly dynamic nature of the system within which they operate. Specifically, these systems are characterised by uncertainty, feedbacks, interdependencies, and chaotic and discontinuous nonlinear relations of their elements (Kauffman 1993; Patten and Jørgensen 1995). That is, these complexities (and decisions made in relation to these complexities) arise from the interactions and interdependencies of a large number of elements rather than being static and isolated. Therefore, when developing and implementing decisions for natural resource management, a suitable methodological framework is required that can address complex, uncertain and dynamic decision problems. Given the prominent role that the human dimension plays in natural resource management (i.e. coupled socio-ecological problems), this framework also needs to address how to elicit and integrate data from the knowledge domain (i.e. expert knowledge) with "Hard" data.

This project aimed to provide and demonstrate a stakeholder-driven assessment of a coastal natural resource management in the context of climate change. Specifically, we aimed to develop two stakeholder-driven (participatory) models (systems conceptualisation and a BBN) for climate change adaptation of the whale watching industry using south-east Queensland, Australia, as a case study. Furthermore, the project aimed to provide information for model development, economic benefits and impacts of whale migration alterations.

## Approach

In this study, we employed a participatory systems approach in identifying key variables and evaluating response strategies. Participatory modelling is the process of incorporating stakeholders, often including the public, and decision makers into an otherwise purely analytic modelling process to support decisions involving complex natural resource questions (Voinov and Gaddis 2008).

Our approach combines two complementary systems techniques: (1) systems thinking for stakeholder-driven system conceptualisation and conceptual model building and (2) Bayesian belief network (BBN) modelling to identify and evaluate management strategies within a probabilistic framework. Throughout the modelling process, continuous involvement of stakeholders in the model building, scenario development and identification of response strategies stages significantly improves the value of the resulting model in terms of its usefulness to decision makers, its educational potential for the public and its credibility within the community (Korfmacher 2001; Johnson 2009).

Systems thinking provides a method 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). The systems approach can be applied to any system and involves the building of analytical models explaining system behaviour, developing a set of strategies that combine observations with the use of models and informed judgements, 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.

BBN modelling (Kjærulff and Madsen 2008), through the underlying Bayes theorem, provides a methodology for integrating the "Expert" knowledge, including from different disciplines (e.g. social, economic, political, environmental), of the participants in a probabilistic framework. Specifically, participants provide the causal structure and underlying conditional probabilities that go into building a functioning BBN resulting in a stakeholder-driven model (the researchers simply acting as the conduit for the development of such a model). The developed model can then be used as a basis for investigating different scenarios through "Top–down" (theory of total probability, e.g. the drivers of some or all of the BBN are known and the effect on the marginal probabilities of the priority node can be assessed) or "Bottom–up" (implementing Bayes theory to obtain posterior estimations of marginal probabilities in the face of new evidence, e.g. evidence could be that the state of the priority node is known and the effect on the driver nodes is investigated).

## Methods

### Preliminary development of a conceptual model

Initially, a systems diagram (conceptual model) of the relationships and variables considered relevant for climate change and whale watching was constructed based on expert knowledge over the course of multiple meetings (Fig. 1). For this, we initially drew upon the multidisciplinary background of the co-authors. We identified four broad modules that the conceptual model could be separated into: climate change, biological, economic and management (see supplementary material). Developing a system diagram based on expert knowledge prior to the engagement with stakeholders was chosen to save discussion time during the workshop.

Conceptual models are important tools in systems analysis. They represent cause–effect relations between elements or sub-systems of the overall system (Loucks and van Beek 2005). They also illustrate where there are feedbacks (pathways that feedback to a point of origin in the system) and where these may interact or link with other feedback loops. Feedback is a process whereby an initial cause ripples through a chain of causation, ultimately to re-affect itself (Roberts 1983). An important tenant of systems analysis recognises that the interaction between these feedback loops is not linear. That is, an identical change in one component may not always cause the same system behaviour as there may be a change in the state of the system, over time.

### Stakeholder engagement: systems model development and evaluation

A stakeholder workshop was held in December 2014 at Griffith University, Gold Coast (Australia), where representatives of the key actors operating within (e.g. tour boat operators, regulators), or alongside (other tourism ventures, non-governmental organisation—NGOs) the whale watching industry were invited using a "Snowballing" approach to participate, collate additional information and further shape the systems model (Goodman 1961). Their task was to evaluate the impact of, and adaptive capacity for, changes in ocean currents and other coincident climatic changes (e.g. increased water temperature, rainfall, wind and wave) on the whale watching tourism industry with a focus on areas for management intervention. The stakeholder workshop consisted of eleven participants representing a selection of stakeholders relevant to the whale watch industry. This included tourism association, operators, local and state government bodies and a non-governmental organisation.

At the start of the workshop, the moderator presents and explains the preliminary conceptual model to the participants (Fig. 1). The boundaries of the conceptual model are then discussed so that the development of the model is focused. The group consensus was to keep the model focused on humpback whales only, whilst acknowledging comments from the participants that dolphins or other marine megafauna species could be a way of adapting to changes (to humpback whale watching) by offering alternatives when whales were not present.

The moderator communicated to the participants that this conceptual model captured external climate and biology factors over which the stakeholders have limited control. It was also communicated that, in contrast, the socio-economic factors included within the conceptual model are endogenous (internal) and can be directly managed (i.e. intervention points). The participants were then encouraged to focus predominantly on the socio-economic factors during the refining and validation process.

The systems conceptualisation was further developed during the workshop and refined to identify and better understand those elements within the system where management intervention is most influential. This process also provided a framework for synthesising the main system components for the key stakeholders, i.e. a shared understanding. This included participants adding new variables to the model and agreeing on the links between variables.

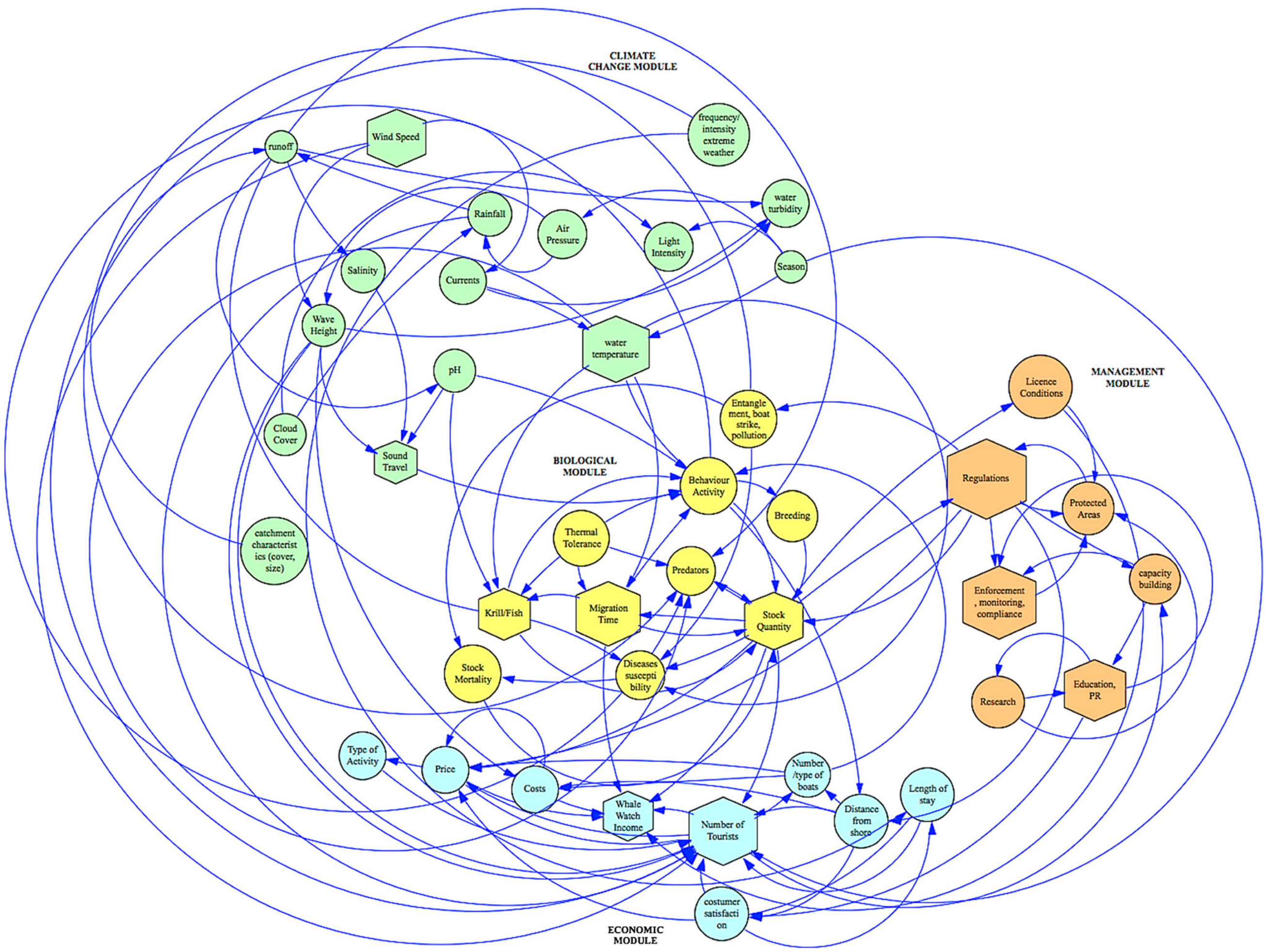


**Fig. 1** Conceptual model for climate change and whale watching based on expert knowledge and revision after stakeholder consultation. The *arrows* in the model indicate direction of influence (one factor increases; the other increases or decreases)

## Stakeholder engagement: Bayesian belief network development

BBN 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. BBN modelling is a methodology that is well suited to representing causal relationships between variables in the context of variability, uncertainty and subjectivity, even when data are sparse or disparate (Nadkarni and Shenoy 2004). The underlying probabilistic framework allows integration of social, economic and environmental variables within a single model (Kjærulff and Madsen 2008). The utility of using BBNs in engaging with experts has recently been demonstrated in climate adaptation (Richards et al. 2013) and sustainable resource research (Tiller et al. 2013). Much of this utility arises from their ability to integrate data (knowledge) across multiple- and trans-disciplinary areas, especially where data are sourced through "Expert opinion" (Kjærulff and Madsen 2008).

The efficacy of using BBNs for capturing this expert opinion is dependent on assigning conditional probabilities (Kjærulff and Madsen 2008; Catenacci and Giupponi 2012; Richards et al. 2013). This step can be improved by using the application (app) App2Adapt, which was used in our study to enhance the process of the whale watch BBN development. It has been deployed successfully in previous research projects (Richards et al. 2014) and was developed in Apple's integrated development environment of Xcode supporting Objective-C source code. This app uses graphical sliders to capture the conditional probabilities rather than relying on directly assigning probabilities, which have been observed to be difficult (Richards et al. 2013).

The development process for the BBN is described in Richards et al. (2013). Briefly, it starts with the workshop participants selecting a "Priority issue" for further assessment. This priority issue is based on discussion amongst the group regarding an important management aspect associated with the whale watching industry in the context of their system (i.e. the systems conceptualisation) and climate change. The participants are then presented with the fundamental steps of developing this BBN including providing information on standard BBN terminology (i.e. *variables*, *nodes*, *states* and *conditional dependence*, see also supplementary material).

The participants are then shown how their priority issue becomes the starting point of the BBN construction process by getting them to discretise it with two states: a *desirable* state and an *undesirable* state. This process transforms the selected priority issue into a variable, which is an important component of BBN development. During this stage, the participants were also provided with information regarding the rules governing the discretisation of BBN variables; specifically, the states must address all possible outcomes, be mutually exclusive and be consistent for that variable (Uusitalo 2007; Richards et al. 2013). Basic examples of discretisation were given such as the quality of media coverage (discretised qualitatively as *reliable* [desirable] or *unreliable* [undesirable]).

It was also highlighted that these states would be broad and qualitative for the purpose of this BBN. Based on this background information on constructing the structure of a BBN, the following steps were provided:

A. Participants selected a maximum of three parent nodes (primary-level variables) by identifying the variables that directly influence their capacity to manage the priority issue and to discretise these with a maximum of two states: a “Desirable” and an “Undesirable” state.
B. Participants then selected a maximum of three parent nodes (secondary level) for each of the primary-level nodes by “Identifying the variables that directly influence these primary-level variables”.
C. Depending on time availability during the workshop, the participants are advised that an additional level of nodes (tertiary-level nodes) can be added to the BBN using the second prompting statement.

The participants were instructed to discretise all variables (nodes) in their BBN with two states: a “Desirable” and an “Undesirable” state. However, it was also stated that there might be instances where it was more informative to assign states that did not necessarily reflect a desirable and undesirable state but rather reflected the two possibilities (e.g. a node representing the *size of a land catchment area* (e.g. for calculating run-off) could have discrete values of small area/large area. This node could then be a parent node for *run-off rate* (high/low)).

We reduced the size of the conditional probability tables (CPTs) by limiting the number of states to two for all nodes and setting maximums for the number of parent nodes (per child node). The conditional probabilities are quantifying the strength of relationships between parent and child nodes.

The result of this process is the development of a directed acyclic graph (a uni-directional graph where there are no cycles or feedback pathways, see also additional material) that is characterised by two to three hierarchical levels above the priority node. The final stage of developing this BBN is populating the associated CPTs. Contrasting the development of the BBN structure, which was based on the collective belief of workshop participants, the CPTs are populated based on individual participant beliefs. These data were obtained through the participants assigning percentages to the CPTs that represented their belief in the strength of these relationships. This was achieved using the iPad app *App2Adapt* (Richards et al. 2014). We then used Netica software (Norsys Software Corp., version 5.12) to develop the belief network and test our model.

### Conditional probability tables

The BBN represents the causal structure component of the model developed by the workshop participants. To extend this to a numerical model, the workshop participants were asked to assign conditional probabilities that quantify (based on their beliefs) the strength of the relationships between directly connected nodes.

The process for this model requires populating four separate conditional probability tables (CPTs) (one CPT for each “Child” node). For this process, we invited the participants to use an iPad application to assign their probabilities (see Richards et al. 2014, for more specific details about the application and the process of assigning conditional probabilities using this tool). After the BBN was populated with conditional parameters, a parameterised BBN was then generated in Netica. Note that an auxiliary “Stakeholder” node was included as a variable within the BBN and represents the effect of individual stakeholder beliefs on the network. Equal weighting has been set for the participants (14.3 %) involved in this step of the model development ($n = 7$) indicating that the conditional probabilities assigned by the different participants are viewed with equal importance in the model. Note that whale operators (Operator) have been separated from non-operators (Stakeholder) in this auxiliary node so that direct industry versus non-direct industry beliefs can be compared and contrasted.

## Results

The outcomes of the stakeholder workshop were a shared cognitive mapped model (the systems conceptual model—Fig. 1) of the whale watching system (in this case study for the Gold Coast in south-east Queensland) a probabilistic-based management model built around a specific priority issue associated with the whale watching industry and that was identified by the workshop participants (the BBN model) and an improved understanding of the key determinants, including climatic variables, influencing the priority issue based on a sensitivity analysis conducted on the BBN model.

### Conceptual model—climate module

The participants highlighted sea level as an element that was missing from the conceptual model that was initially presented at the workshop. However, after some discussion this element was not included due to its perceived long-term and indirect influence on the whale watching industry. The frequency and intensity of weather events were noted as a relevant and additional variable that is linked to the number of tourists, e.g. tourists are likely to either stay away from a holiday destination or decide not to participate in whale watching in response to a weather event. As an example, the 2011 flooding in Brisbane (van den Honert and McAneney 2011) was mentioned when the total number of available tourist became low.

The participants also noted that air temperature was absent from the preliminary conceptual model. However, after group discussion, it was agreed that water temperature was seen as a better indicator of the effects of temperature (than air temperature).

Water depth and $CO_2$, which were included in the preliminary model presented to the workshop participants, were removed by the workshop participants. $CO_2$ was removed because it was seen as an overarching factor. For water depth, this is a known determinant of turbidity along with sound, currents, water temperature and productivity. It was agreed that turbidity was not regarded as an issue for whale watching in south-east Queensland and probably not for whales either, but there was an acknowledgement that this might change for future whale watching activities (such as swimming with whales). Light intensity was seen as relevant for Antarctic food/krill in the biological module and remained in the climate change module. Other relevant variables that were not discussed included stable weather conditions and frontal systems.

Climate change processes were identified as important drivers within the updated conceptual model. The most important elements identified by the participants were water temperature, wind speed and direction (in this order). It was noted by the participants that cyclone events are currently outside of the whale season, but this could change in the future. From an operator's perspective, wind speed and direction were viewed as the most relevant factor. However, water temperature is linked to wind and weather events and also a strong driver of food availability for whales and migration timing.

Participants also noted the importance of location (spatial context) in influencing the relative importance of the different elements within the climate module of the conceptual model. Specifically, the participants indicated that coastal morphology was an important condition of determining which elements were more important drivers within the model. They exemplified this by highlighting that an enclosed bay would have less problems with wind speed but stronger influences of catchment run-off. River run-off/rainfall is also linked to catchment size, and participants agreed that large amount of run-off can push animals further offshore (Dalla Rosa et al. 2012).

### Conceptual model—biological module

There was a discussion amongst the participants that an overall slowing of the humpback whale population growth had been observed, leading to a short discussion about the importance of krill in Antarctica. From this discussion, the elements "Migration timing", "Stock quantity" and "Krill/fish" were seen as the most important drivers for the biological module in this order. Some minor changes were made (see Table 1), and the biological module was regarded as complete otherwise.

### Conceptual model—management module

After discussion with the workshop participants, a few new links were added in the management module including "Monitoring/compliance" linked to "Enforcement" and "Regulations" linked to "Stock quantity", "Capacity building" and "Protected areas" (Table 1). It was pointed out by the participants that the factor "Licence condition" is associated with costs, but currently the market is self-regulated outside of protected areas. It was discussed that, initially, permits had a positive influence on the whale watch industry, stabilising the industry and bringing it into a mature market. The belief was expressed by some that mature markets do not need enforcement given the level of education. Nevertheless, customer expectation can lead to a push for limits and operators can be in breach of the 100 m distance and other regulations (Nature Conservation and Other Legislation Amendment and Repeal Regulation, No. 1, 2013).

The variables "Regulation", "Monitoring" and "Education/PR" were considered the most important elements in this module. For example, regulations can be a powerful tool to increase whale stock quantity and help in reducing pressure on whales. The factor "Regulations" also includes protection status such as threatened species status. "Capacity building" was regarded as dependent on regulation and education processes. The role of community involvement was discussed and seen as included in the "Education/PR" factor through NGO work.

**Table 1** Overview of new, deleted and changed variables in the expert derived conceptual model after stakeholder consultation. The "Management module" is highlighted in light grey, the "Biological" module in dark grey, the "Climate Change" module in black and the "Economic" module is not highlighted

| New variables and links | Changed variables | Deleted variables |
|---|---|---|
| "Stock Quantity" linked to "Regulations" | "Shark nets, boat strikes, pollution" to "Entanglements, boat strikes, pollution" | "Water depth" |
| "Monitoring/compliance" linked to "Enforcement" | "Stock quantity" includes population dynamics | "$CO_2$" |
| "Regulations" linked to "Stock quantity", "Capacity building" and "Protected areas" | "Regulations" also include safety regulations | |
| "Customer Satisfaction", "Length of Stay", "Number and type of boats" added | "Capacity" to "Capacity building" | |
| "Education/PR" linked to "Distance from shore" and "Capacity building" | "Law enforcement" shortened to "Enforcement" | |
| "Number of tourists" linked to "Capacity building" and "Education/PR" | "Education" extended with "Public relations (PR)" | |
| "Number and type of boats" linked to "Length of stay", "Customer satisfaction" and "Price" | | |
| "Distance from shore" linked to "Number of boats" | | |
| "Customer satisfaction" linked to "Education/PR" and "Distance from shore" | | |
| "Price" linked to "Length of stay" | | |
| "Season" linked to "Number of tourists" | | |

### Conceptual model—the economic module

Three new variables were introduced as an outcome of the discussion amongst the participants. These factors included "Number and type of boats" that are used in the whale watch operator fleet, the "Length of stay" of tourists and "Customer satisfaction". Additional links were also established focusing on the new factors (Table 1). It was further discussed that entanglement of whales on the Gold Coast can be a negative advertisement for the industry, but may still be beneficial for increasing the market as it provides publicity for the whales (no quantification was made for the link).

Some questions arose about the "Number of boats" being related to climate variables, and it was agreed that they are indirectly related. "Distance from shore" (travel distance to whales) was important for marketing and promotion. This factor can be influenced by northerly winds (wind speed/direction) and warm temperatures, which can push the whales further offshore requiring longer travel time for whale watching. This was identified as an acute climate variability factor influencing the whale watch industry.

The number of tourists (not necessarily numbers of passengers) and income (annual profit for all operators) were seen as the most influential factors within the economic module.

Adaptation options for the industry that emerged during the discussion with the participants about the preliminary conceptual model included reduction in travel distance for whale watching through planning (search directions, communication with other operators), offering different types of whale watching experience, improved use of online marketing to increase customer numbers, offering different types of sales, and creating a work environment that had high flexibility. Increasing the market and income were mentioned as the most effective ways to counteract climate change.

### Determination of the priority management issues for Bayesian network development

During the second phase of the workshop, participants discussed what priority management issues were important for whale watching under climate change. Different issues were expressed with themes of resilience, adaptation and sustainability suggested from the workshop facilitation team leading to a discussion about the presence of whales and general access to natural resources by the participants.

A longer discussion about the "Priority Issue" to build the BBN around was led by the two tour operators. One operator questioned how climate change could be directly linked to the management of the whale watching industry. A big concern was that climate change is only changing at a slow incremental rate. This led to discussion about how climate change could be included in the assessment of the "Priority Issue", which is framed around managing the whale watching industry under climate change. It was suggested that "Public perception/expectations of whale watching industry" could be the "Priority Issue" and that climate change could play out through these perceptions/expectations. Further discussion followed about the perceptions (what people perceived the whale watching industry to be like, e.g. ecotourism) and expectations (what people expect to happen when they go whale watching, e.g. expecting to see a whale breach) of customers. This led on to how these expectations are managed by the operator such as preparing the customer for the tour. Profitability of the industry under climate change was then suggested by one of the tour operators as an alternative priority issue because this was itself dependent on people's perceptions/expectations. This was then changed to "Profitability of the whale watching industry" (Fig. 2), which became the priority issue.

### Primary- and secondary-level nodes

Primary-level nodes for the BBN are those that are directly linked to the priority issue node and were selected by the participants to be "Customers", "Costs" and "Whales". "Customers" was the first node selected and followed on from the initial discussions about the priority node and whether this was about customer perceptions/expectations. The sentiment was that customers were an important (and direct) part of the profitability of the industry from the perspective of the operators. "Costs" represented the overheads and related to "Fixed" and "Variable" costs.

"Whales" were the last of the three primary-level nodes selected and came after some discussion about whether there was a third node (at this level) at all. One stakeholder (non-operator) highlighted that "Whales" needed to be included at some level as this was about whale watching and the presence/absence of whales. Humpback whales could shift their migratory pathways or, at least, significant changes to the timing of the migration could occur resulting in a shorter or less successful operating period for whale watching. This leads to further discussion about whether the number of whales was directly linked to profitability (i.e. the priority issue) or whether it acted on the priority issue through other nodes. In the end, there was consensus that it was directly linked to the priority issue of profitability.

Secondary-level nodes for the BBN included "Weather", "Marketing", "Competition" for time, "Fuel", "Wages", "Assets", "Weather", "Timing" and "East Australian Current (EAC)" (see supplementary material for definition of these variables). The discussed climate change adaptation tools suggested by workshop participants are summarised in Table 2.

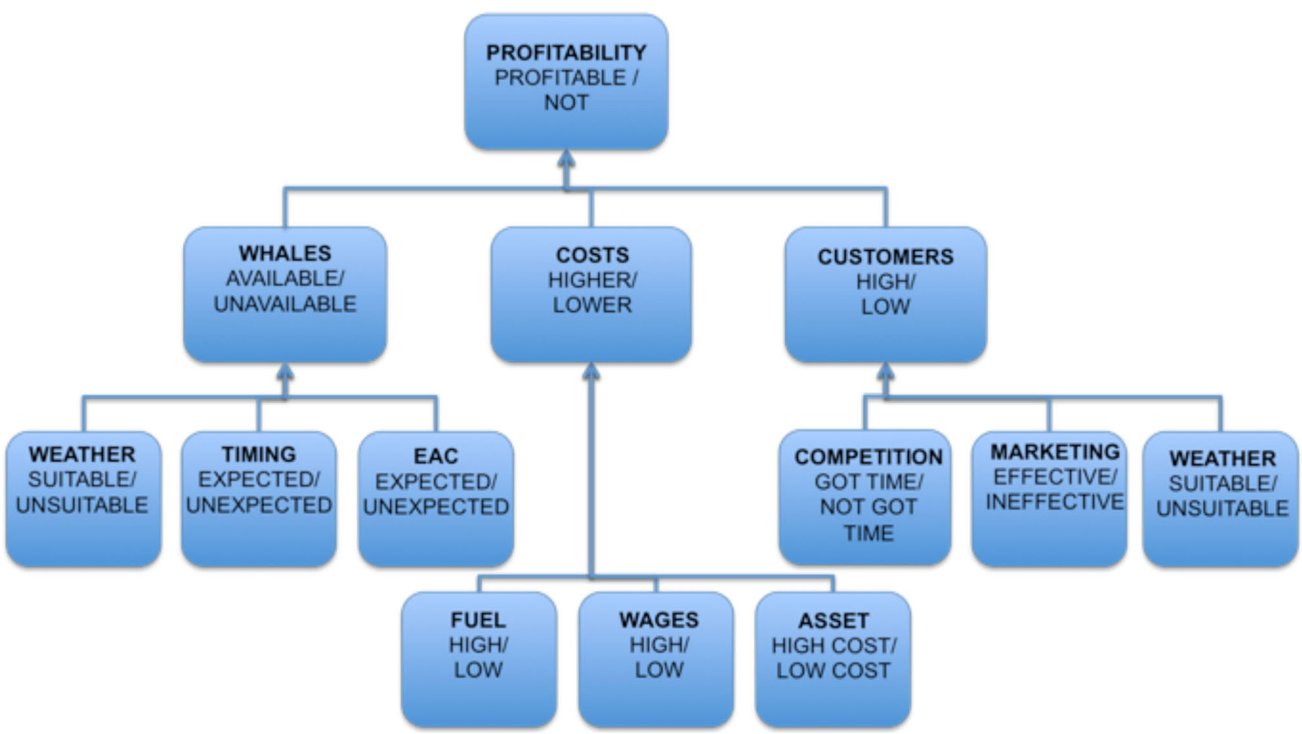


**Fig. 2** Bayesian network nodes for the defined priority issue (Profitability) with primary and secondary levels of "Parent nodes" as determined by the workshop participants. Whale presence/absence was expressed as available or not available. Whale availability was determined by season (includes type of experience which is not necessarily dependent on number of whales)

**Table 2** Summary of discussed climate change adaptation tools suggested by workshop participants

| Adaptation tool/variables | Strategies |
|---|---|
| "Customer" | Increase the number of customer through whole sale, online sale and innovative sale strategies |
| "Costs" | Reduce costs by only running full boats |
| "Profitability" | Ensure profitability by reducing costs and increasing customer numbers |
| "Whales" | Ensure whales are present through protection of species |
| "Assets" (Costs) | Reducing/controlling cost of boat and other infrastructure |
| "Wages" (Costs) | Reducing through technology and innovation |
| "Fuel" (Costs) | Reducing fuel cost by using different type/size/fleet size vessel, e.g. sail boat versus motor boat. Reduce search time through collaboration with other operators |
| "Weather" (Customers) | Improve ability to get the customers to the whales, e.g. larger vessel, covered deck |
| "Marketing" (Customers) | Influencing perceptions/expectation of the customers in "Selling the product". Managing customers and educating them such as preparing the customer for the tour |
| "Competition" | Manage competition for customer over limited time and with other whale watch operators |

### Summary of group sensitivity analysis

The parameterised BBN (see supplementary material) was subjected to a sensitivity analysis to determine which of the nodes within the model had the most influence on the priority issue probabilities.

The three primary-level nodes were observed to have the greatest influence on "Profitability". The node "Customers" was found to have the greatest influence on "Profitability", followed by "Whales" (i.e. whether they are available or unavailable for whale watching) and then "Costs" (see supplementary material).

For the secondary-level nodes, the main influences on "Profitability" were mediated through "Customers" and "Whales", respectively. Conversely, "Fuel", "Wages" and "Asset" (parent nodes for "Costs") were the least influential nodes on "Profitability" in the BBN. The dominant path of influence was from "Competition" to "Customers" to "Profitability". The next dominant path was from "Weather" to "Whales" to "Profitability". "Weather" also exerted influence on "Profitability" via "Customers" (see supplementary material).

The sensitivity analysis showed that the influence on the auxiliary node representing stakeholder beliefs (Stakeholders) was only moderate, having less influence on "Profitability" than five of the other nodes ("Customers, Whales, Cost, Competition, Weather"). This indicates that the beliefs of the seven participants were generally convergent, i.e. the probabilities assigned by the participants were generally consistent across the group.

### Sensitivity analysis—CPTs of the two operators

Sensitivity analyses were carried out to determine the sensitivity of the node "Profitability" to the other nodes based on the probabilities supplied by the two workshop participants who are tour operators (see supplementary material). This allowed for comparison between the operators and the participants as a whole. The main influence was through "Whales", which was the dominant node. The main node acting through this was "Weather" (i.e. Weather → Whales → Profitability). This was a good indication about the strength of perception by the two stakeholders about the role the weather plays in influencing profit, i.e. "Weather" has stronger influence than "Costs" and "Customers", even though "Weather" is an indirect effect on "Profitability" (i.e. typically indirect effects are weaker because they are acting through other nodes—here, the dominance of "Whales" on Profitability coupled with the dominance of "Weather" on "Whales" means that there is a strong link between "Weather" and "Profitability"). In addition, customers were also a strong influence (behind "Whales" and "Weather") and "Weather" also played a prominent role through "Customers" (although the context for weather is slightly different).

## Discussion

This is the first study to bring together stakeholders from the whale watching industry to develop a response to climate change. 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). Using two modelling techniques (systems thinking and Bayesian belief network modelling), we synthesised available knowledge from experts and stakeholders to address interconnections between variables and uncertainties. The participatory modelling process helped to build capacity for adaptation by helping the industry bring together its knowledge within a systems framework and analyse how different socio-ecological components join together, including feedback pathways for understanding system behaviour. The participatory approach applied in this study using systems thinking and BBN allowed for developing several adaptation options, and the method is applicable to other regions with whale watching. They provide a good way to tackle problems in fields of high uncertainty. Outcomes from similar projects in natural resource management have been promising (Bosch et al. 2007).

### Adaptation and management options

The main focus of identifying potential adaptation options was through the socio-economic-management module of the systems model (i.e. where management interventions can be made).

Feedback from the workshop participants included the importance of taking into account spatial context (coastal morphology). Therefore, it is important that the role of this spatial context is incorporated in management plans and potential impacts when considering climate change. For example, adapting to changed rainfall patterns (and runoff) will be of greater importance for operators in coastal embayments with regard to whale movements and time (costs) spent looking for whales. Conversely, oceanic-based operators will be more affected by changes in wind patterns, which has potentially adverse implications for customer comfort (perceptions and expectations).

Following on from the spatial context, it emerged from the workshop (both in the systems conceptualisation and the BBN development) that there is the perception of a strong relationship between whales (presence or absence) and the weather conditions. Access to whales (and ultimately, based on the BBN, profitability) is driven by knowing where the whales will be ["Fuel costs" and "Customers"] and when they will be there ["Timing"]. Recent observations coupled with future climate projections of whale migration and weather patterns suggest an increase in variability in whale location and timing. Whales may arrive earlier in the season or leave weeks earlier before the season ends depending on weather and current patterns. Storms and rainy days during the dry season may also increase (Abbs and McInnes 2004) and reduce the number of days for whale watching.

Therefore, increased knowledge is needed about the interrelationships between weather and whale movement patterns and how this will react to evolving climate patterns. The whale watching industry is in a strong position to contribute much of this knowledge, and therefore, ongoing and/or improved collaboration with research organisations is needed. This should include "Citizen science" approaches to research, e.g. Whale Trails app (Meynecke 2014). Any efforts aiming to protect and increase the whale population should also be supported by the industry.

Climate adaptation (and adaptive capacity) has been framed around minimising negative impacts and taking advantage of positive impacts (Pörtner et al. 2014). Therefore, there also needs to be capacity within the whale watching industry to negate the adverse effects of change in whale locations/timings and to also take advantage of any opportunities that might emerge. In the workshop, it was suggested that to counteract extreme weather events, alternative tours (e.g. dolphin watching, bird watching) could be developed and made available when whales are not present.

A flexible pricing framework and different type of whale watch experience were also seen as a good response strategy to overcome unpredictable weather events. This also addressed the issue of limited time of customers and customer expectation. In general, a work environment of high flexibility is needed to adequately deal with increasing extreme weather events. To counteract alteration in whale migration, it was proposed to reduce search time using early starts and communicate with other operators about the direction of search. This would also allow a reduction in travel distance for whale watching.

The increase in flexibility such as running more trips and different type of trips also increases maintenance costs and needs to be brought back through the number of customers. To counteract increased costs of flexibility and to help increase customer numbers, it was suggested to improve the use of online marketing through improved market share (wholesale distribution, moving from the local market, access and maintaining relationships to agents). Overall, increasing the market and income were mentioned as the most effective ways to counteract the impacts of climate change.

### Resilience of the whale watch industry to climate change

Based on the study findings, the south-east Queensland whale watch industry shows some resilience to climate change but very little pathways and direct strategies to address impacts and opportunities. In its current state, the industry might not have the capacity to adequately respond to major shifts in whale migration and weather. Furthermore, it might also lack the capacity to respond to changes that are likely beneficial for the industry, such as high numbers of calves being born—an area that appears to require further attention. There is a lack of knowledge and need for continuous monitoring of whales to enable a response to changes. A similar situation may be found in other popular whale watch regions for example on the east coast of North and South America.

A successful increase in flexibility associated with higher costs to respond to climate change is dependent on innovative and proactive management. The resilience depends on the types of trips and types of tourist, geographic region and species of cetacean. It is therefore necessary to build knowledge about tourist expectations and regional whale distribution and ecology to further improve capacity of the industry. Whale watching tourists are not homogenous in their values, attitudes, expectations, motivations or demographic backgrounds and respond differently to the same experience (Hoyt 2001; Lambert et al. 2010). A detailed prediction for how the humpback whales are likely to respond to climate change is not yet available. Based on current knowledge, whale watching in cooler regions is expected to experience changes before whale watching in other areas (indirect affects of climate change on infrastructure and economy maybe higher elsewhere), given the higher rates of temperature change (Pörtner et al. 2014). Migrating species are exposed to a wide range of environmental conditions and are likely to avoid unfavourable conditions relatively fast compared to isolated populations.

## Conclusions

In this project, we used a stakeholder workshop and expert knowledge to synthesise available information and suggested adaptation tools for the whale watch industry under climate change. Combining the two methods, system thinking and Bayesian belief network modelling, allowed for developing several adaptation options (e.g. targeting alternative species, investing in the fleet). The capacity of the industry to implement these adaptation options can be dealt with through increased knowledge about whale dynamics by supporting research through a greater alliance between tourism and research and citizen science. Closing current knowledge gaps and lobbying at local and state government levels to support proactive whale watch management are important steps to build up adaptive capacity. In order to maintain profitability, the whale watch industry needs to increase its flexibility, and an effort to keep stable tourist numbers by local council, tourist associations, and state government is also required. Maintaining regulations to protect cetaceans is also essential components.

The relevance of these outcomes is regional specific; however, the method used in this case study is applicable to other whale watching regions around the world. The method cannot replace quantitative data collection and relies on the experience and knowledge of the workshop participants.

The impacts and opportunities deriving from climate change can vary significantly between regions. However, there is sufficient evidence that humpback whales are shifting migration timing, changing resting and calving locations (Ramp et al. 2015), and that weather patterns are becoming less predictable (e.g. more storm events and periods of rain) (Pörtner et al. 2014). Our case study demonstrated that the whale watch industry is vulnerable to climate change to different extents but that there are multiple intervention points, especially in the economic and regulation sector. The sooner potential impacts and opportunities are addressed, and the more likely climate change can be adequately adapted to. However, if no adaptation is undertaken (i.e. "Business as usual"), this will likely result in reduced income for whale watch operators based on lower customer numbers and higher operational costs.

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## References

Abbs DJ, McInnes KL (2004) The impact of climate change on extreme rainfall and coastal sea levels over south-east Queensland. Part 1: analysis of extreme rainfall and wind events in a GCM. CSIRO Atmospheric Research, Gold Coast

Bindoff NL, Willebrand J, Artale V, Cazenave A, Gregory J, Gulev S, Hanawa K, Le Quéré C, Levitus S, Nojiri Y, Shum CK, Talley LD, Unnikrishnan A (2007) Observations: oceanic climate change and sea level. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Bosch OJH, King CA, Herbohn JL, Russell IW, Smith CS (2007) Getting the big picture in natural resource management-systems thinking as 'method' for scientists, policy makers and other stakeholders systems research and other stakeholders. Behav Sci 24:217–232. doi:10.1002/sres.818

Catenacci M, Giupponi C (2012) Integrated assessment of sea-level rise adaptation strategies using a Bayesian decision network approach. Environ Model Softw 44:1–14. doi:10.1016/j.envsoft.2012.10.010

Cisneros-Montemayor AM, Sumaila UR, Kaschner K, Pauly D (2010) The global potential for whale watching. Marine Policy 34:1273–1278. doi:10.1016/j.marpol.2010.05.005

Corkeron PJ, Connor RC (1999) Why do baleen whales migrate? Marine Mamm Sci 15:1228–1245. doi:10.1111/j.1748-7692.1999.tb00887.x

Cunningham PA, Huijbens EH, Wearing SL (2012) From whaling to whale watching: examining sustainability and cultural rhetoric. J Sustain Tour 20:143–161. doi:10.1080/09669582.2011.632091

Dalla Rosa L, Ford JKB, Trites AW (2012) Distribution and relative abundance of humpback whales in relation to environmental variables in coastal British Columbia and adjacent waters. Cont Shelf Res 36:89–104. doi:10.1016/j.csr.2012.01.017

Goodman LA (1961) Snowball sampling. Ann Math Stat 32(1):148–170. doi:10.1214/aoms/1177705148

Poloczanska ES, Babcock RC, Butler A, Hobday AJ, Hoegh-Guldberg O, Kunz TJ, Matear R, Milton DA, Okey TA, Richardson AJ (2007) Climate change and Australian marine life. Oceanogr Mar Bio 45:407–478. doi:10.1201/9781420050943.ch8

Hoyt E (2001) Whale watching 2001: worldwide tourism numbers, expenditures and expanding socioeconomic benefits. International Fund for Animal Welfare, Crowborough

Jackson JA, Zerbini A, Clapham P, Garrigue C, Hauser N, Poole M, Baker CS (2006) A Bayesian assessment of humpback whales on breeding grounds of Eastern Australiaand Oceania (IWC Stocks E, E1, E2 and F). Paper SC/A06/HW52 presented to the IWC Scientific Committee. International Whaling Commission, Cambridge

Johnson M (2009) Public participation and perceptions of watershed modeling. Soc Nat Resour 22:79–87. doi:10.1080/08941920802220347

Kauffman S (1993) The origins of order: self-organization and selection in evolution. Oxford University Press, Oxford

Kjærulff U, Madsen A (2008) Bayesian networks and influence diagrams: a guide to construction and analysis. Springer, New York

Knowles T, Campbell R (2011) What's a whale worth? Valuing whales for National Whale Day. International Fund for Animal Welfare (IFAW) & Economists at Large, Melbourne, Australia

Korfmacher KS (2001) The politics of participation in watershed modeling. Environ Manage 27:161–176. doi:10.1007/s002670010141

Lambert E, Hunter CP, Pierce GJ, MacLeod CD (2010) Sustainable whale- watching tourism and climate change: towards a framework of resilience. J Sust Tour 18:409–427. doi:10.1080/09669581003655497

Loeb VJ, Santora JA (2015) Climate variability and spatiotemporal dynamics of five Southern Ocean krill species. Prog Oceanogr 134:93–122. doi:10.1016/j.pocean.2015.01.002

Loucks DP, van Beek E (2005) Water resources systems planning and management: an introduction to methods, models and applications. Unesco, Paris

Meynecke J-O (2014) Whale trails—a smart phone application for whale tracking. In: Ames D, Quinn N (eds) 7th international congress on environmental modelling and software, San Diego, California, USA, 2014. International Environmental Modelling and Software Society (iEMSs) pp 1–7

Nadkarni S, Shenoy PP (2004) A causal mapping approach to constructing Bayesian networks. Decis Support Syst 38:259–281. doi:10.1016/s0167-9236(03)00095-2

Noad MJ, Dunlop RA, Paton D, Cato DH (2011) Absolute and relative abundance estimates of Australian east coast humpback whales (*Megaptera novaeangliae*). J Cetacean Res Manag 3:243–252

Patten BC, Jørgensen SE (1995) Complex ecology: the part-whole relation in ecosystems. Prentice Hall, Englewood Cliffs

Pörtner H-O, Karl DM, Boyd PW, Cheung WWL, Lluch-Cota SE, Nojiri Y, Schmidt DN, Zavialov PO (2014) Ocean systems. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 411–484

Ramp C, Delarue J, Palsbo PJ II, Sears R, Hammond PS (2015) Adapting to a Warmer ocean—seasonal shift of baleen whale movements over three decades. PLoS One 10:e0121374. doi:10.1371/journal.pone.0121374

Richards R, Sano M, Roiko A, Carter RW, Bussey M, Matthews J, Smith TF (2013) Bayesian belief modeling of climate change impacts for informing regional adaptation options. Environ Model Softw 44:113–121. doi:10.1016/j.envsoft.2012.07.008

Richards RG, Sahin O, Sano M, Meynecke J-O, Tiller R (2014) App2Adapt: using tablet technology to elicit conditional probabilities for Bayesian belief network. In: Ames DP, Quinn N (eds) 7th international congress on environmental modelling and software. San Diego, California, pp 18–23

Roberts N (1983) Introduction to computer simulation: the system dynamics approach. Addison-Wesley, Reading

Smith JN, Grantham HS, Gales N, Double MC, Noad MJ, Paton D (2012) Identification of Humpback whale breeding and calving habitat in the Great Barrier Reef. Mar Ecol Prog Ser 447:259–272. doi:10.3354/meps09462

Tiller R, Gentry R, Richards R (2013) Stakeholder driven future scenarios as an element of interdisciplinary management tools; the case of future offshore aquaculture development and the potential effects on fishermen in Santa Barbara, California. Ocean Coast Manag 73:127–135. doi:10.1016/j.ocecoaman.2012.12.011

Uusitalo L (2007) Advantages and challenges of Bayesian networks in environmental modelling. Ecol Model 203:312–318. doi:10.1016/j.ecolmodel.2006.11.033

van den Honert RC, McAneney J (2011) The 2011 Brisbane floods: causes, impacts and implications. Water 3:1149–1173. doi:10.3390/w3041149

Vang L (2002) Distribution, abundance and biology of Group V Humpback whales Megaptera novaeangliae: a review. The State of Queensland Environmental Protection Agency, Brisbane

Voinov A, Gaddis EJB (2008) Lessons for successful participatory watershed modeling: a perspective from modeling practitioners. Ecol Model 216:197–207. doi:10.1016/j.ecolmodel.2008.03.010

von Bertalanffy L (1950) An outline of general system theory. Br J Philos Sci 1:134–165. doi:10.1093/bjps/I.2.134