Baran E., Jantunen T. 2004 Stakeholder consultation for Bayesian Decision Support Systems in environmental management. Proceedings of the ***Regional Conference on Ecological and Environmental Modeling*** *(ECOMOD 2004), Universiti Sains Malaysia, 15-16 September 2004, Penang, Malaysia. In press.*

STAKEHOLDER CONSULTATION FOR BAYESIAN DECISION SUPPORT SYSTEMS IN ENVIRONMENTAL MANAGEMENT

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Abstract. *Environmental management is a field where the number of variables, their interactions and feed-back loops require tools to integrate information, build scenarios and support decision-making. Among the various kinds of Decision Support Systems, Bayesian Belief networks have proven to be quite useful as they can integrate quantitative information as well as qualitative expert knowledge. Beyond knowledge integration, the consultations also help clarifying what is at stake, how variables interact and what are the conflicting interests.*

Gathering expert knowledge requires consultations, with a particular approach constrained by modelling requirements. In this paper based on our experience we focus on the technical aspects of such stakeholders' consultation. We describe in detail the steps of the consultation, we analyse the methodology (selection of stakeholders, collective building of a model structure, probabilities elicitation, etc). Then we review the possible pitfalls and problems encountered in the process. We ultimately propose generic guidelines for stakeholders consultation in view of building Bayesian models for environmental management.

1. Introduction

In recent years, decision support systems (DSS) have been developed to integrate the best available knowledge for informed decision-making. Among the various kinds of DSS, Bayesian networks have proven quite useful as this modeling approach can integrate quantitative information and data as well as qualitative expert knowledge (Jensen 1996, Baran & Cain 2001, Reckhow 2002).

Environmental management, i.e. the management of water and land for the sustainable use of natural resources by people, is a field where multiple disciplines meet and needs often conflict. On technical grounds, the number of variables, their interactions and feed-back loops require tools to integrate information and to assess outcomes of a given decision, which in most cases is beyond the reach of individual experts (Varis & Fraboulet-Jussila 2000, 2002, Redpath *et al.* 2004,).

The stakeholder consultation process consists in identifying the variables considered relevant in the system to be managed, in determining the cause-effect relationships and the weight to be given to each variable or priority. This process can be done by a few experts (e.g. Peterson & Evans 2003, Baran *et al.* 2003) but also provides an opportunity to bring together views and experiences of multiple stakeholders from various backgrounds and interest groups (Borsuk *et al.* 2001, Baran *et al.* 2004). Moreover, quantitative data are rarely available over a sufficient period of time for statistical analysis, especially in developing countries, and in such cases expert knowledge is the best available resource. Another advantage of this process is that it provides a framework for reasoning and facilitates identification and examination of underlying assumptions. Beyond the integration of information, the consultation can help stakeholders and policy makers to better foresee the consequences of their decisions, and to take into account conflicting interests and ideas (e.g. Marcot *et al.* 2001, Rieman *et al.* 2001, Staker 2003).

More generally, a stakeholders consultation favors public acceptance of the management tools developed, and thus increase their chances of being used in actual management (Ellison 1996).

Actually when dealing with "democratic" decision-making in environmental management, two levels of consultation might be necessary: the first one to integrate the technical information about the environment, natural resources and socioeconomic aspects; the second one to address social concerns at a political level, before a decision is ultimately taken. In this paper we are focusing only on the first level of stakeholders' consultation, for which recommendations about modalities are quite scarce in the literature (except the extensive review by van Asselt & Rijkens-Klomp in 2002), and we propose some guidelines for such consultation in the particular case of a Bayesian modelling approach.

2. Bayesian networks

Bayesian networks (also known as Bayes nets or BBN - Bayesian Belief Networks) were developed in the mid-90s as DSS for financial risk assessment and medical diagnostics. They consist of defining the system studied as a network of variables, which are connected by links expressed in terms of probabilities (Figure 1). These variables can be either quantitative (e.g. “Flooded area”) or qualitative (e.g. “Management strategy”). For each variable a small number of classes are defined (e.g. Flood duration "more than 45 days" or "less than 45 days"). Once the network has been parameterized (an operation called "elicitation of probabilities"), the software can calculate the probability of an output given the weight put on each variable and parameter of the system.

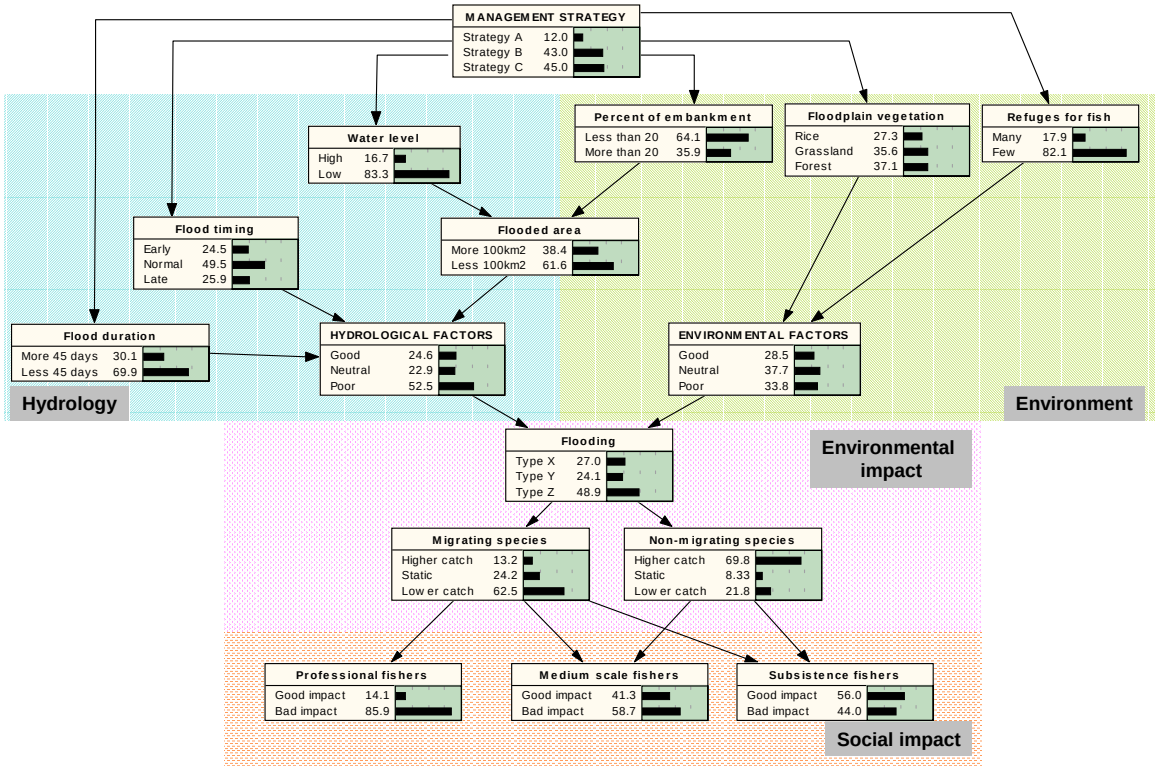

Figure 1: Basic example of Bayesian Decision Support System applied to tropical floodplain fisheries.

A review of softwares and freewares to build Bayesian networks are available online at:
http://www.ia.uned.es/~fjdiez/bayes/software.html
http://www.stat.washington.edu/almond/belief.html

3. Consultation process to build a Bayesian network

Two main approaches to stakeholder consultation consist in computer-mediated questionnaires, as opposed to open discussions, however Kaptein & Van Tulder (2003) acknowledge that there is no "one best way" to consult stakeholders.

Computer-mediated communication (e.g interactive questionnaire) is beneficial in tasks requiring a great diversity of inputs from participants The cost and speed of acquiring advice is better, and the results, being already formatted, are easier to automatically synthesize (the main source of bias residing in the questionnaire design).

In the other hand, gathering of stakeholders and open discussions are more likely to produce higher-quality information and results (Wilkins *et al.* (2002), Beierle 2002). Another advantage of the face-to-face approach is that it brings the participants to develop effective work relationships and interpersonal trust. The rest of this paper, reflecting our experience, will emphasize stakeholders meetings and their practicalities rather than computer-based consultations.

The model-building and stakeholder consultation process can be divided into several steps:
i) Modelers' task: identification and selection of the stakeholders;
ii) Consultation round. Objective: identify outstanding issues and relevant variables;
iii) Modelers' task: creation of a computer-based framework of interacting variables;
iv) Consultation round. Objectives:
- get feed-back on the model framework and modify it accordingly;
- define the relevant states for each variable;

v) Modelers' tasks:
- integrate stakeholders' comments;
- feed the model's quantitative variables with hard data;
- identify relevant states and probabilistic links between quantitative variables

vi) Consultation round. Objectives:
- get feed-back on the conclusions reached about quantitative variables;
- define the probabilities of interactions between qualitative variables;

vii) Modelers' tasks: integrate stakeholders' comments and fine-tune the model
viii) Consultation round. Objectives:
- provide feed-back to stakeholders
- run the model
- analyse and comment scenarios

Training of stakeholders in model operation can also be considered as an ultimate step; the user-friendliness of most Bayesian softwares allows any computer-literate person to do so in a few hours.

4. Stakeholders selection: who, how many?

A stakeholder is understood here as a person with a specific stake, experience or interest in the topic being addressed. A stakeholder can be a government official, a research scientist, an NGO member, an extension officer or a practitioner such as a fisher or a farmer.

The group of stakeholders selected should cover a broad range of field experts (farmers, fishers, foresters, game wardens, etc) and scientists (ecologists and engineers, agronomists, socio-economists) as well as social workers (e.g. developers, extensionists).

An option described by Ravnborg and Westerman (2002) consists of using a combination of individual interviews and public meetings to identify all the different stakeholders and their perceptions. During a first round of individual interviews the initial stakeholders are asked general questions as well as whom he/she thinks might disagree with his/her views. This is used to identify other stakeholders. In a second round of interviews stakeholders are invited to comment on the answers given during the first round. Comparing and contrasting different perceptions and asking nominations are repeated until no new information or categories are forthcoming. This methodology considerably improves interactions and understanding among stakeholders, but is time-consuming and costly (Gregory *et al.* 2002).

Within a group of stakeholders consulted, it is necessary to ensure a diversity of cultures, education levels, disciplines, genders, ages and income level as these parameters also affect how people participate, listen and value others opinions and challenge others views. In practice all these requirements cannot be simultaneously met, and the best possible blend should be sought. A compromise consists in gathering views from a few decision-makers, a number of technicians and representatives from local committees, and a few "field experts", i.e. experienced fishers or farmers.

Stakeholders should also be selected in relation to the scale addressed: for instance commune level stakeholders should be consulted in priority about commune issues as they often prove uncomfortable or vague about provincial or regional level issues. This also means that the number of consultations should be proportional to the scale addressed. Last, in the group composition it might be necessary to also take into account political considerations (Cain *et al*. 2003).

The number of stakeholders to consult depends on the topic and experts availability, and has ranged from a few to hundreds. Too many stakeholders can contribute to information overload, whereas consulting too few generates a bias in the vision and understanding of the system (Gregory *et al.* 2002). Nevertheless, one can consider that the number of stakeholders should not be less than three and should preferably be an odd number in order to facilitate a majority vote on issues that are difficult to agree upon. When consultations are done on the field, gathering 10 to 15 persons is a good compromise between cost, practicalities, diversity of expertise and group dynamics. Actually the total number of stakeholders consulted should be in relation to the scope and breadth of the research/management question addressed. In that regard a consultation corresponding to the

sequential building of specific components of the model (e.g. ecological, socioeconomic, etc.) can be envisaged, while not forgetting that the integration of several sub-models will require the participation of all the stakeholders concerned.

5. Group consultation options and pitfalls

To be successful the consultation process needs to be clearly defined before the beginning of the consultation. In case there is a large number of stakeholders, those should be allowed to choose the intensity and knowledge level at which they want to participate (workshop, interviews, email forum, etc.). It is advantageous to send out agendas and/or working papers before the consultation so all participants have time to prepare for the consultation and acquaint themselves with the material especially if language barriers exist. In theory the participants should be asked before the consultation what sort of information they expect to receive; this can ensure that the participants feel part of the process and can also directly benefit from the results (Gregory *et al.* 2003). In practice and in developing countries, stakeholders are most often unaware of what DSS consist in, and getting them involved requires an official requisition through administrative channels, or an incentive.

If possible the consultation should involve a professional moderator, in particular when a large number of stakeholders are involved. His/her role is to ensure that the stakeholders agree on a common framework, to challenge the experts' first expression of probabilities, to confront different views, to let stakeholders reach compromises, to remind the stakeholders of the causal chains and issues dealt with the model and also to prevent modelers from influencing experts by the early expression of technical constraints (Fenton *et al.* 1999). The presentation of computer models to the group should also be done by a moderator rather than by a modeler. In this way the role of the moderator is clearly only to facilitate the discussions among the participants while not providing expert information (Kasemir *et al.* 2000).

In countries where models are initially developed by foreign experts, the use of international languages such as English or French during consultations can be a serious barrier for the field practitioners to contribute their expertise (Jackson & Bungard 2002). It is imperative to ensure the possibility for stakeholders to discuss issues in their native language, which implies the presence of a translator for interactions with foreign experts. When consultation is done in local language, experience shows that the most efficient configuration is to have a two moderators/translators and two modelers. Then one moderator facilitates the discussion while the other translates for modelers, which prevents losing momentum during the discussions as well as disruptions during the translation. On the modelers side, one expert modifies the model in real time while the other takes notes of arguments and justifications; both send questions back to the stakeholders.

In places where culture strongly prohibits disagreeing publicly with someone of higher social status, it might be important, in order to cover the diversity of views, to split a big stakeholders group into smaller groups homogenous in terms of social status, race, age or gender, or even to convey intermediate stakeholders meetings on the basis of homogenous social criteria. During a consultation, there can also be unintentional focus on loyalty and maintenance of internal cohesiveness of the group which can result in a decision making process failing to explore in detail the minority views and ideas (Gregory *et al.* 2001). As highlighted in section 3, it is good practice to request feedback after each phase about the consultation process itself in order to make changes if necessary.

Because long and frequent meetings are rarely possible, a practical option consists in establishing a core group of stakeholders that are ready to significantly invest time and effort into this exercise (Cain *et al.* 2003). In fact, it might be useful to provide participants with moderate financial incentives for their involvement in a process that can be intense and time-consuming (Kasemir *et al.* 2000). This group will then have a good understanding of the modeling process and consequences of their decisions, which also strengthens capacity building in developing countries. Overall, the role of extension and teaching during the consultation process should be considered and where possible incorporated, because stakeholders consultation process often reveals gaps in knowledge, especially with lower education stakeholders. The disadvantage of the core group option is that it is less representative of all views and will generate fewer ideas. Also, beyond interested individuals it has to be properly representative of policy makers.

During the consultation process practicalities such as having enough breaks should be remembered, because people unaccustomed to consultations and computers get tired quickly and lose interest in the process. This will influence the accuracy and reliability of the information gathered. Also moderators should always explain the

terms used and clarify further when necessary, especially if there seems to be difficulties in understanding topics, terminology or percentages (i.e. quantity or quality).

6. Issues specific to Bayesian networks

When eliciting probabilities, probability tables that result from the combination of several driving variables should be as manageable as possible. Therefore, the variables must be as few as possible, usually no more than four (Cain 2001; Lynam et al. 2002; Stamelos et al. 2003). In such a configuration, representing the child node as a pie chart in which the contribution of each parent node must be defined has proven most efficient during stakeholders consultations. However it can be useful to let them classify first the importance of each parent variable for the child node (1, 2, 3…), and only after this begin discussing the exact corresponding percentages. When opinions differ about the contribution of each parent node to a child node, then voting is a possible solution.

Anderson (1998) provides a review of the pitfalls of the probabilities elicitation procedure, in particular from a psychological perspective (e.g. conjunction fallacy, overestimation). In his online review, Fenton (http://www.dcs.qmw.ac.uk/~norman/) identifies additional psychological fallacies as well as dangers inherent to probabilistic computation. These pitfalls are recurrent in probabilities elicitation with stakeholders, and should be always kept in mind during consultations.

Another problem commonly encountered is an excess of 50s (i.e. 50% - 50%) in answers. The use of 50s increases with questions addressing threatening topics and they are given more frequently by teenagers and lower education adults (De Bruin et al. 2002).. There are several ways to avoid this problem:

i) provide a “no idea” option.

ii) presenting the numerical options in a ruler like form diminishes the overuse of 50-50 and encourages the participants to be more precise.

iii) correcting data through the beta function. This function redistributes responses from participants to match the best-fit curve. Responses from overused categories (50%) are reallocated to under-used ones. The drawback of this method is that an assumption has to be made about the distribution of the answers into categories.

iv) correcting data by the averaging method that redistributes the excess 50-50 answers into other categories in proportion to the importance they already have. This method is not unbiased as it reinforces the dominant opinions or categories.

7. Conclusion

Bayesian Belief Network modeling has proven its usefulness for combining expert knowledge and quantitative data into powerful and accessible analyses. This approach provides a framework for effective dialogue between stakeholders as well as a learning tool for understanding the consequences of decisions. Several authors have highlighted the importance of the consultation process (e.g. Moss *et al.* 2000, Borsuk *et al.* 2001, Soncini-Sessa *et al.* 2002, Peterson & Evans 2003) and its role in bridging the gap between the provision of scientific advice. Recent examples show that the use of stakeholder consultation for environmental management using DSS is becoming more common, and this requires specific and carefully designed consultation processes. However defining modalities of this consultation in view of minimizing biases and maximizing representativeness of the model is still a theme for research (Arthington *et al.* 2004).

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