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BIODIVERSITY REVIEW

Practical solutions for making models indispensable in conservation decision-making

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ABSTRACT

Aim Decision-making for conservation management often involves evaluating risks in the face of environmental uncertainty. Models support decision-making by (1) synthesizing available knowledge in a systematic, rational and transparent way and (2) providing a platform for exploring and resolving uncertainty about the consequences of management decisions. Despite their benefits, models are still not used in many conservation decision-making contexts. In this article, we provide evidence of common objections to the use of models in environmental decision-making. In response, we present a series of practical solutions for modellers to help improve the effectiveness and relevance of their work in conservation decision-making.

Location Global review.

Methods We reviewed scientific and grey literature for evidence of common objections to the use of models in conservation decision-making. We present a set of practical solutions based on theory, empirical evidence and best-practice examples to help modellers substantively address these objections.

Results We recommend using a structured decision-making framework to guide good modelling practice in decision-making and highlight a variety of modelling techniques that can be used to support the process. We emphasize the importance of participatory decision-making to improve the knowledge-base and social acceptance of decisions and to facilitate better conservation outcomes. Improving communication and building trust are key to successfully engaging participants, and we suggest some practical solutions to help modellers develop these skills.

Main conclusions If implemented, we believe these practical solutions could help broaden the use of models, forging deeper and more appropriate linkages between science and management for the improvement of conservation decision-making.

Keywords

Communication, conservation, modelling, structured decision-making, trust, uncertainty.

INTRODUCTION

Decision-making for conservation management often involves evaluating risks when ecological knowledge is incomplete and outcomes are uncertain (Regan *et al.*, 2005). Decision-making under uncertainty can be difficult, even paralysing when set against a backdrop of competing social, economic and political objectives (Ludwig *et al.*, 2001; Burgman, 2005; Knight *et al.*, 2006). Models offer a way of dealing with uncertainty and complexity in decision-making. Models are a purposeful representation of a system, hypothesis or experiment and include any useful form of abstraction to assist thinking

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(Starfield *et al.*, 1990). Good modelling practice offers a systematic, rational and transparent platform for synthesizing existing knowledge, exploring the consequences of management alternatives and identifying and evaluating uncertainty (Starfield, 1997; Burgman, 2006). Detailed quantitative models are not a requirement for all decisions, as both qualitative and quantitative representations of a system can effectively support decision-making. Sound models can be formulated using empirical data or structured expert judgement and should be answerable to data and the fundamental rules of probability and formal logic.

There are numerous examples where models have helped conservation management decisions, and some of these include the successful re-introduction of multiple populations of the hihi in New Zealand (Armstrong *et al.*, 2007); the successful re-introduction of gray wolves and management of harvest quota for elk in Yellowstone National Park, USA (Varley & Boyce, 2006); the successful conservation efforts to protect the Kemp's ridley sea turtle in the Gulf of Mexico from anthropogenic stressors (Crowder & Heppell, 2011); and informing the adaptive management of trawl fishing in the north-west shelf of Australia to mitigate impacts to marine biodiversity (Sainsbury *et al.*, 1997, 2000). However, despite their demonstrated benefits, models are still not used in many conservation decisions (Cowling *et al.*, 2003; Roux *et al.*, 2006; Knight *et al.*, 2008). Instead, conservation decisions are often supported by unstructured subjective judgments, such as intuition, personal experience or unaided expert opinion (Sutherland *et al.*, 2004; Pullin & Knight, 2005; Cook *et al.*, 2010).

Unstructured subjective judgments can lead to opaque, biased conservation decisions that rest on hidden assumptions and individual agendas (Burgman *et al.*, 2011). The rejection of models in favour of such unstructured judgments can lead to unintended and unacceptable social, economic, political and environmental outcomes. In many cases, heeding model predictions over unstructured subjective judgments could have averted significant social and/or environmental costs of conservation decisions. Examples include: the decline and local extinctions of Iberian lynx populations (Palomares *et al.*, 2011); the invasion of the zebra mussel throughout North American waterways, incurring vast economic and ecological impacts (Clark *et al.*, 2001; Strayer, 2008); and large-scale tree mortality and ecosystem collapse in North American pine forests as a result of a rapid range expansion of mountain pine beetles (Willms, 2010).

We are not claiming that all models used to support conservation decisions are good. There are many cases where ill-informed or inappropriate models have led to suboptimal conservation outcomes. For example, decisions based on fisheries models that overestimated stock sizes led to the overfishing and eventual collapse of Canadian stocks of Atlantic cod, which in turn resulted in major social and economic impacts (Walters & Maguire, 1996). Improbable assumptions in a model used to inform Florida panther management produced inaccurate inferences about habitat suitability that permitted development in important habitat areas (Beier *et al.*, 2006). In these cases, models were inadequate to support the decision context.

The question is why are models adopted to support decision-making in some instances, and not in others? In this article, we explore this question by assessing common objections to using models in decision-making from several fields of environmental management. We address a lack of guidance in the literature by presenting a series of practical solutions to help modellers substantively overcome these objections. Our aim is to assist modellers improve the effectiveness and relevance of their work in supporting conservation decision-making.

COMMON OBJECTIONS TO THE USE OF MODELS IN DECISION-MAKING

We reviewed scientific and grey literature for evidence of the views and attitudes towards the use of models by those who commonly participate in environmental decision-making. We provide a simplified definition of participants, acknowledging that participants can fall into multiple roles: decision-makers (those with the legal/regulatory right or responsibility for the decision), stakeholders (those involved in or affected by a decision) and experts (scientists and others with direct experience or knowledge of the problem at hand; Burgman *et al.*, 2011).

We searched published surveys and papers that document the opinions of participants, and a range of government and organization guidelines and reports that provide commentary on the use of models in decision-making. We searched literature from the past two decades from the fields of conservation, fisheries, water resource and weed management, climate science and biosecurity using the web-based resources Google, Google Scholar and Thomson Reuters Web of Science. Nine common objections to the use of models in environmental decision-making emerged, which relate to three broad categories: (1) the role of models in decision-making, (2) modelling practice and (3) model outputs. We have selected two key quotations that we believe best illustrate each of the nine common objections, which are shown in Table 1.

The role of models in decision-making

Organizations may simply prefer unstructured subjective judgements (such as unaided expert opinion), from either internal decision-makers or relevant experts, to a model's predictions (Objection 1, Table 1). This may be because decision-makers: have a well-established relationship with trusted experts (Cullen *et al.*, 2001); are unfamiliar with working with models (Pidgeon & Fischhoff, 2011); believe that models do not result in better decisions (Hajkowicz, 2007; Marshall *et al.*, 2010); fear that models may diminish their autonomy in the decision-making process (Heagney *et al.*, 2011); or feel that modellers, as organizational outsiders, have disparate agendas (Gibbons *et al.*, 2008).

Table 1 Common objections to the use of models in decision-making

The role of models in decision-making

1. We don't need models for decision-making, we have experts

(i) Where there is a '*lack or inconclusiveness of fundamental science, or the lack of data, or where data reliability is questionable… quantitative risk analyses cannot be sensibly undertaken. Where this is the case, expert opinion is used*' (Beale *et al.*, 2008).

(ii) I am '*good at doing what* [I] *do and… trust* [my] *own decision*' (a common perception of graziers (decision-makers) cited in Marshall, 2010).

2. Developing and using models in decision-making is too resource intensive

(i)'*Reserve selection algorithms are comparatively resource-hungry. In most countries conservation is grossly under-funded, and for many organizations the cost of hardware, an expert operator, and the experimentation required may inhibit the use of reserve selection algorithms (even if the software itself is free)*' (Prendergast *et al.*, 1999).

(ii)'*Water managers, due to lack of resources and time have a need for better model-based tools as a means to support increasingly complex decision making but that same lack of time and resources prevents them from being able to invest time and resources into the models, if the researchers cannot invest the time in providing the type of non-technical requirements (such as maintenance, model re-calibration; documentation, confidence, usability) they require*' (Borowski & Hare, 2007).

Modelling practice

3. Models do not represent my conceptual understanding of the decision context

(i)'*Models did not adequately incorporate or simulate managers' experiential knowledge*' (Heagney *et al.*, 2011).

(ii)'*Grower decisions include too many judgment factors and life situation variables for the models to be useful*' (Wilkerson *et al.*, 2002).

4. Models focus on environmental considerations of the decision context, but fail to capture the social, economic and political factors which influence conservation management options

(i) '*I still think the human mind is better at processing this information if you have all the information*' (a statement made by decision-maker in Hajkowicz, 2007).

(ii) '*Currently available models are too simple because they do not consider the effects of cultural practices… on weed competitiveness when making recommendations*' (Wilkerson *et al.*, 2002).

5. Models are either too complicated or too simple

(i)'*Although scientific models are simplifications of reality, many remain so complex that they are seen as black boxes instead of transparent analytical tools*' (De Smedt, 2010).

(ii) '*From a biological standpoint… currently available models are too simple*' (Wilkerson *et al.*, 2002).

6. There are insufficient data to do quantitative modelling

(i)'*To work effectively, sophisticated methods of site selection usually require higher-quality data than most managers can ever expect to have*' (Prendergast *et al.*, 1999).

(ii)'*Quantitative (numerical) risk assessments are not common in a management context… because the data requirements are onerous, especially considering that little information is available about the impacts of many introduced marine species*' (Hewitt *et al.*, 2011).

7. Inadequate data quantity/quality leads to inaccurate model predictions

(i)'*Models themselves are currently too inaccurate to be of value in real-time decision making because insufficient data have been used in model development for them to accurately predict competitive effects and yield losses in most situations*' (Wilkerson *et al.*, 2002).

(ii) Decision-makers are '*not convinced that seasonal climate forecasts can be very accurate…*' and that there is '*not much point in a seasonal forecast that is vague*' (a common perception of graziers (decision-makers) cited in Marshall *et al.*, 2010).

Model outputs

8. I don't understand the way scientists communicate

(i)'*It is often difficult understanding scientific information*' (a common perception of graziers (decision-makers) cited in Marshall *et al.*, 2010).

(ii)'*Another constraint identified by water managers… was the lack of communication between water managers and researchers… Neither are they sharing the same language for expressing results or the requirements of models*' (Borowski & Hare, 2007).

9. Model outputs are too uncertain for decision-making

(i)'*Water managers see a good potential to use models but they displayed an obvious lack of confidence in them –even in some of their own in-house models… this lack of confidence can be overcome by investing resources into better forms of model uncertainty analysis and its communication*' (Borowski & Hare, 2007).

(ii)'*Many agency people apparently view admission of uncertainty as admission of weakness, and assume that the outcome of admitting weakness will be inaction or ineffective compromise policy… It is very difficult to convince people who adopt such views that they will gain more credibility with political decision makers by openly admitting uncertainty*' (Walters, 1997).

Many decision-makers also view model development and use as too resource (time and/or money) intensive (Objection 2). In some cases, particularly for small-scale environmental problems, this might be true (Possingham, 2009). Alternatively, decision-makers may have limited access to the requisite technical expertise, and outsourced modelling may be prohibitively expensive (Prendergast *et al.*, 1999).

Modelling practice

Decision-makers may consider models to be wrong, inaccurate or inappropriate for a number of reasons. For instance, when the model does not represent decision-makers' conceptual understanding (Objection 3) or adequately capture the social, economic and political elements of a decision

(Objection 4). Models may be judged as too simple or too complex to be useful to environmental decision-making (Objection 5), for example, models are seen as too complicated when they are unintuitive (Pidgeon & Fischhoff, 2011) or as too simple because not all relevant factors are incorporated/used with adequate detail (Wilkerson *et al.*, 2002). Lastly, models may be considered to have limited capacity for decision support when there is a lack of data to construct a quantitative model (Objection 6) or because inadequate data quality/quantity leads to inaccurate model predictions (Objection 7). In some cases, these points are used to justify qualitative analysis (Beale *et al.*, 2008) or the use of unaided expert opinion (Dinerstein *et al.*, 2000; Beale *et al.*, 2008).

Model outputs

Participants' acceptance of model outputs, such as predictions of ecosystem effects and evaluation of the effectiveness of management alternatives, can be compromised by poor communication throughout the modelling process by modellers (Objection 8). For instance, modellers can fail to cater to different levels of technical understanding and reasoning styles of their audience (Anderson, 2001; McNie, 2007). Decision-makers can also feel overwhelmed when presented with multiple possible outcomes from model outputs (Pidgeon & Fischhoff, 2011) and can struggle with how to use information about uncertainty in decision-making (Objection 9). In fact, some decision-makers are averse to openly admitting uncertainty (Walters, 1997).

By classifying common objections to models into these three main categories, we note that many of the nine objections may apply to more than one category. For example, objections relating to model uncertainty may affect participants' views of the role of models in decision-making, modelling practice and their acceptance of final model outputs.

PRACTICAL SOLUTIONS

We believe the common objections outlined above are symptoms of three fundamental issues: (1) misconceptions about the role of models in decision-making, (2) poor modelling practice and (3) a lack of effective communication and/or trust between modellers and decision-makers. Here, we present a set of practical solutions to address these fundamental issues (summarized in Table 2). These solutions are based on theory, empirical evidence (comparative studies and surveys/interviews) and best-practice examples of the use of models from conservation science, natural resource management and social science.

Table 2 Practical solutions to help overcome the common objections to using models in decision-making for conservation management

Practical Solutions	Helps address objections:
1. Dispel common misconceptions about modelling	1, 3–7
2. Use a Structured Decision Making/Adaptive Management framework to guide good modelling practice	
(i) Use the problem formulation stage to develop clear objectives and management alternatives for the decision context (see Fig. 1)	3, 4
(ii) Model consequences with participants to adequately capture the complexity and uncertainty of decisions (see Fig. 1)	1, 3–9
3. Improve the social process of decision-making by engaging with decision-makers, stakeholders and experts in participatory decision-making	1–9
4. Improve communication	
(i) Practice Daniels & Walker's (2001) seven key competencies of communication (Box 1)	1–9
(ii) When adequate communication skills are lacking seek specialist training or use a skilled facilitator	1–9
(iii) Present scientific outputs in brief and accessible formats	8, 9
(iv) Use storytelling (images, scenarios and personal narratives) to enhance communication	8, 9
5. Build trust	
(i) Establish frequent personal contact with decision-makers, for example face-to-face meetings, telephone calls and emails	1–9
(ii) Actively engage participants in decision-making and promote genuine opportunities for involvement and collaboration	1–9
(iii) Communicate the outcomes of the decision-making process to gain trust from the wider community	1–9

Dispel common misconceptions about modelling

Modellers should work to dispel common misconceptions about models in decision-making (*Practical solution 1*; Table 2). Achieving this requires modellers' to develop an understanding of participants' perceptions of the role of models in decision-making and an awareness of their own role in the decision-making context. We recommend that modellers anticipate objections such as those listed below, and emphasize the following points in response. By explicitly addressing these misconceptions early in the model building process, modellers will provide opportunities to dispel common misconceptions about models and should achieve greater buy-in from participants regarding the use of models to support decision-making.

1. *Models diminish the autonomy of decision-makers (Objection 1):* Models are tools for helping us think, not arbiters in decision-making contexts. They provide decision support

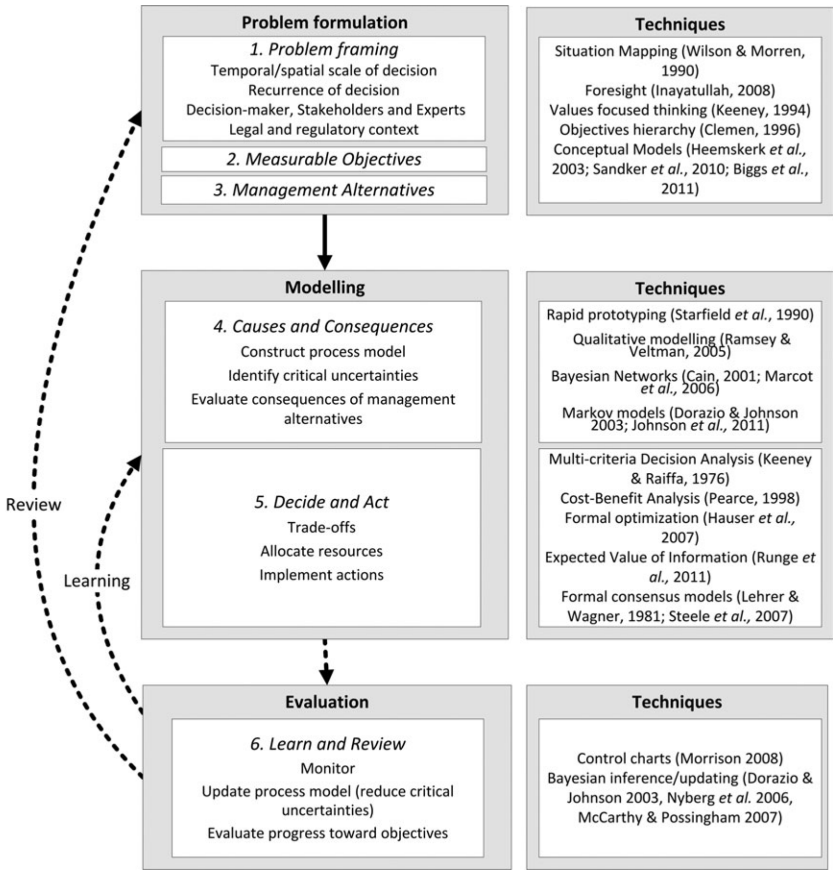

Figure 1 The Structured Decision Making/Adaptive Management framework (based on Walters (1986) and Gregory *et al.* (2012), and adapted from Wintle *et al.* (2011)). Dashed lines indicate the additional stage and feedback loops of Adaptive Management. Details of the steps within each stage are listed, and examples of modelling techniques that can assist the decision-making process are listed alongside each stage.

and should not replace decision-makers (Starfield, 1997). It is important that both decision-makers and modellers are clear that a modeller's work is embedded in the decision-making context. That is, just because a modeller has built a model does not mean they have ownership of the decision context; rather, they are only assisting the decision-making process.

2. *Models are too simple or complex and do not represent decision-makers' conceptual understanding or incorporate all of the considerations of the decision context (Objections 3–5):* This misconception can be valid, particularly when modellers have failed to develop a model that is appropriate to the decision context. Other than improving modelling practice, modellers should communicate that all models are simplifications of reality, vary in detail and complexity and need not accurately or faithfully represent reality to be useful (Box, 1979; Starfield *et al.*, 1990). It is important to also highlight that individuals' mental models, which reflect their conceptual understanding of a decision-making context, are also simplifications of reality and will differ based on individual values, perspectives and biases (Vennix, 1999; Biggs *et al.*, 2011). This is particularly relevant to discuss with decision-makers, as they too should realize that their own perception of a decision-making context will be subject to a number of assumptions and biases, which may differ from the perceptions of others (Burgman *et al.*, 2011).

3. *Data are insufficient for modelling, or data quantity/quality will generate inaccurate predictions (Objections 6 and 7):* A lack of data does not preclude model building (Starfield *et al.*, 1990; Leung & Steele, 2013). Decisions are often based on incomplete data, and models are able to use knowledge in the form of structured expert judgement and/or empirical data (Walters, 1986; Krueger *et al.*, 2012). Models should always reflect the constraints of the decision-making context (Hajkowicz *et al.*, 2009; Possingham, 2009), and modellers must ensure that models do not make predictions that are more accurate than the information used to build them. The choice of modelling technique will also depend on whether qualitative or quantitative predictions are required for the decision context.

Improve modelling practice

Structured decision making (SDM) and adaptive management (AM) can provide a sound foundation for improved use of models in decision-making (*Practical solution 2*; Fig. 1; Holling, 1978; Walters, 1986). These frameworks systematically incorporate participant values, objectives and knowledge in decision-making (Keeney, 1996; Runge *et al.*, 2011). SDM frameworks utilize a broad suite of decision-analysis tools to aid rigorous, transparent and logical decision-making, some of which are listed in Fig. 1. AM is a form of SDM, required when decisions are recurrent and hampered by critical uncertainty, and aims to maximize management and learning outcomes (Williams *et al.*, 2009; Runge, 2011).

Problem formulation

Problem formulation involves appropriately framing a problem to account for the decision context, by including participant values and regulatory requirements (*Practical solution 2i*; Fig. 1; Keeney, 1994; Runge, 2011). This process should involve developing clear objectives and feasible management alternatives. This is a creative and iterative process to stimulate and clarify thinking about management objectives, constraints, threats/risks and their consequences (Keeney, 1994). This is a critical step, as the objectives drive the rest of the decision-making process (Keeney, 1996). Modellers should be involved in problem formulation so that they have a clear understanding of the decision context when developing their model to evaluate management alternatives (see *Model consequences*).

When modellers engage participants at this stage, they enhance their prospects to address relevant environmental, social, economic and political values, improve representation of different conceptual understandings and facilitate a collective understanding of the problem (thus overcoming Objections 3 and 4; Sandker *et al.*, 2010; Biggs *et al.*, 2011). In Figure 1, we provide some qualitative techniques that can be used to elicit structured expert judgements to assist in problem formulation. We highlight the role of values-focused thinking (Keeney, 1994) and conceptual models (visual qualitative models; Heemskerk *et al.*, 2003) which assist with clarifying participants' thinking, promote exploration of individual biases and assumptions of the decision context and assist in developing a shared understanding of the problem. For example, Sandker *et al.* (2009) conducted visioning exercises with participants to explore future scenarios of the decision context, using conceptual models and participant's knowledge of historic events. This provided a foundation for participants to develop objectives and explore management alternatives in subsequent modelling steps.

Model consequences

The purpose of models is to explore the consequences of management alternatives, in relation to the objectives identified in the problem formulation stage (*Practical solution 2ii*; Walters, 1986; Williams *et al.*, 2009). These are models of cause-and-effect, which are often referred to as process, or system models. Decisions often are made under severe uncertainty. Typically, it is difficult to make these decisions subjectively, as transparency of the decision-making process can be compromised (Burgman *et al.*, 2011). Both quantitative and qualitative models can be used to represent existing knowledge and identify, explore and resolve the critical uncertainties that impact on management decisions (Ramsey & Veltman, 2005; Rumpff *et al.*, 2011; Runge *et al.*, 2011). In Figure 1, we highlight different modelling techniques that are commonly used to model consequences. The choice of modelling technique should depend on the available ecological and management information, and whether qualitative or quantitative predictions are required for the decision context. Whilst informing and validating model parameters with empirical data is ideal, a lack of empirical data does not prohibit model building (Starfield *et al.*, 1990). Structured expert judgement, acquired from elicitation techniques, can be used to provide estimates of model parameters and their uncertainties or to supplement empirical data (Kuhnert *et al.*, 2010; Speirs-Bridge *et al.*, 2010; Runge *et al.*, 2011; Krueger *et al.*, 2012; Martin *et al.*, 2012). Within AM, models can be updated with new data from experimental manipulation or from monitoring relevant system variables under the existing management regime. Targeted knowledge updating is particularly useful in resolving the impacts of uncertainty on management decisions (Evaluation step and Learning and Review feedback loops in Fig. 1; Williams *et al.*, 2009; Runge, 2011).

Modellers can improve the relevance of their model to the decision context by involving the original participants throughout the model building process. This will promote shared understanding of the concepts of cause-and-effect relationships underlying the system. Recognition that models can appear logically unintuitive to participants without modelling experience may prompt modellers to select a particular modelling technique for specific circumstances. For example, modellers may opt for techniques that retain the visual conceptual model used to formulate the problem, such as Bayesian Networks (Nyberg *et al.*, 2006; Rumpff *et al.*, 2011), which allow direct translation of data into a quantitative model format. Retaining this visual aspect can be useful to highlight to participants the model's information and assumptions (Lynam *et al.*, 2007), thus avoiding the perception that models are black boxes (Objection 5).

There are relatively few published examples that illustrate the involvement of participants in modelling consequences, followed by the clear implementation of a model in conservation decision-making. Arguably the most well-known example is the AM of Mallard ducks by the US Fish and Wildlife Service, where managers were involved in the process of structuring hypotheses and models to determine appropriate harvest rates of waterfowl (Nichols *et al.*, 2007). Other examples include Irwin & Mickett Kennedy (2008) and Lynam *et al.* (2010), who describe the process of engaging participants in workshops to structure and parameterize Bayesian Networks to support AM projects for river and estuarine ecosystems. Runge *et al.* (2011) and Moore & Runge (2012) also engaged managers in problem formulation and elicitation of predictions of the consequences of management alternatives, using expected value of information (EVOI) analysis to assess the need for AM of critically endangered species and invasive weeds, respectively.

Despite modellers' best efforts, decision-makers may still resist using model outputs for decision support. There can be many reasons for this, including the influence of unspecified competing objectives, or the effect of emotionally charged or highly politicized situations. Modellers may find they have little influence in these situations (Lee, 1993). However, in some such situations, a modeller may have the opportunity to address competing objectives from participants that are revealed through the modelling process. Once revealed, competing objectives can be used to reformulate the problem and remodel consequences.

The modelling techniques we highlight in this section cover a range of qualitative and quantitative approaches, some of which are much more complex and resource intensive than others. Most importantly modellers should realize that a model is not an end in itself (Lynam *et al.*, 2007); rather, it should be used for decision support, and sit within the constraints of the decision-making context (Hajkowicz *et al.*, 2009; Possingham, 2009). By choosing a model that is fit-for-purpose, following a SDM framework, involving participants and demonstrating the benefits of using models in decision support, modellers will begin to overcome many decision-makers' preferences for unaided expert opinion over models (Objection 1), doubts about modelling practice (Objections 3–7) and model outputs (Objections 8–9).

Improve the social process of decision-making

A SDM framework provides an opportunity for active participation, but on its own does not encompass the means of mediating the social processes and dynamics of decision-making (Cundill *et al.*, 2012). Given that social aspects of decision-making are not part of conventional scientific training (McNie, 2007), we discuss the importance of engaging participants, improving communication and building trust.

Participatory decision-making, by engaging participants in model building in workshops for example, has been shown empirically to improve management decisions in three key ways (*Practical solution 3*): (1) knowledge-management benefits—participants contribute new information, ideas and solutions which improve the quality of decisions (Beierle, 2002; Bijlsma *et al.*, 2011), (2) social benefits—participants' learning is enhanced, and they have a greater sense of ownership of decisions, leading to greater social acceptance and uptake of decisions (Wassen *et al.*, 2011; Muro & Jeffrey, 2012), and (3) environmental benefits—through improved conservation outcomes (Brody, 2003; Sultana & Abeyasekera, 2008).

Whilst the involvement of participants in the initial stages of decision-making can promote buy-in to the modelling process and decision outcomes (Stauffacher *et al.*, 2008; Sandker *et al.*, 2009; Franzen *et al.*, 2011), the mere inclusion of participants is not enough. The participatory process must also be effective (Raymond *et al.*, 2010). For example, active involvement of participants in formulating problems and contributing to management decisions (as recommended in *Improve modelling practice*) can improve the social benefits of decision-making (Yaffee & Wondolleck, 2000; Beierle, 2002); a balanced representation of participants (i.e. involving experts from different disciplines and various stakeholder groups) can improve social, knowledge-base and environmental benefits of decision-making (Newig & Fritsch, 2009; Arvai & Froschauer, 2010); and, involving participants with prior knowledge or involvement in the decision context can improve the knowledge-base of decisions (Alberts, 2007).

Modellers should be aware that participatory model building can become challenging when participants hold divergent views (Vennix, 1999; Biggs *et al.*, 2011) or when participants believe they play dual roles in a decision-making context (e.g. both an expert and stakeholder; Burgman, 2005). There may be little that modellers can do to remedy such challenges through the model building process, although improving communication and building trust will help (see *Improve communication* and *Build trust*). Decision-makers should also play an active role in anticipating and facilitating such challenges from the outset. In general, modellers will be in a position to highlight the benefits of using models in decision support and to address the common objections to models (Objections 1–9) when they actively engage participants in decision-making.

Improve communication

Good communication is the foundation for effective engagement, collaboration and the acceptance of management decisions (Roux *et al.*, 2006; Welp *et al.*, 2006; Reed, 2008). Poor communication, in contrast, can lead to detrimental environmental outcomes. For example, the damaging biological invasions mentioned earlier (e.g. Clark *et al.*, 2001; Willms, 2010) might have taken a different course if early risk communications were judiciously incorporated into decision-making.

As noted above, various modelling techniques can assist in mediating the decision-making process and thus ease communication challenges (Fig. 1). In addition, Daniels & Walker's (2001) seven key competencies in communication can help modellers gain a deeper understanding of what is required to be a good communicator (Box 1; *Practical solution 4i*). Unsurprisingly, empirical evidence suggests that one-way communication is less effective at engaging participants compared with two-way, face-to-face communication (Borowski & Hare, 2007; Newig & Fritsch, 2009). Active listening and demonstrating respect, openness, honesty and understanding also create more constructive interactions (Lewis & Relnsch, 1988; Tuler & Webler, 1999).

Modellers should seek specialist training in communication or employ a skilled facilitator, when communication skills to competently engage participants are lacking (*Practical solution 4ii*; Daniels & Walker, 2001; Gibbons *et al.*, 2008; Reed, 2008). Some useful guidelines for group facilitation can be found in Robinson (2005) and NOAA (2007), and see Franco & Montibeller (2010) for guidelines on facilitated modelling techniques from the field of Operational Research. Cash *et al.* (2006) recommend that people who are known and trusted by decision-makers and stakeholders are the

Box 1: Seven key competencies in communication (adapted from Daniels & Walker (2001)).

1. *Active listening* to demonstrate respect and to be exposed to others' views.
2. *Questioning and clarification* to elicit and share information and to build an understanding of others views, preferences and positions for representation in models.
3. *Feedback* to enhance a learning process and focus discussion on matters of substance, relationships or procedure.
4. *Self-monitoring* to heighten awareness of our own behaviour and its effect on others (e.g. being sensitive to cultural, identity and relational differences).
5. *Dialogue* to develop shared understanding. This involves open two-way communication, where all parties suspend judgment, and actively and empathetically listen.
6. *Model constructive communication behaviour* to serve as an example for others to replicate.
7. *Collaborative/constructive argument* to pool the knowledge and analytical skills of all parties and to deepen and transform individual knowledge.

most effective facilitators. Conversely, empirical evidence suggests that facilitators should be independent of the decision-making organization and modeller (Mostert *et al.*, 2007). Modellers and decision-makers should assess the suitability of different facilitators on a case-by-case basis.

Communicating model outputs is a crucial aspect of participant engagement (Cash *et al.*, 2006; Borowski & Hare, 2007). Modellers should be able to pitch their message to different audiences, catering to different levels of technical experience (Anderson, 2001; Lach *et al.*, 2003). Brief outputs written in accessible/plain language are effective for communicating with nonscientific audiences (*Practical solution 4iii*; Janse, 2008). Modellers should practise creative communication of model outputs, such as storytelling, where images, scenarios and personal narratives are used to resonate with participants and give them a broad understanding of the decision context, regardless of their prior knowledge of the system (*Practical solution 4iv*; Moser & Dilling, 2004; Marx *et al.*, 2007; Somerville & Hassol, 2011).

By investing time in communicating well with participants, modellers will provide participants with a genuine opportunity to contribute to the model building process. Practising good communication will also give modellers an opportunity to highlight the relevance of their role in decision-making, promote the acceptance of model outputs and assist with dispelling many of the common objections to models (Objections 1–9).

Build trust

Trust is an essential element of effective decision-making. A lack of trust can be damaging. For example, a lack of mutual trust between scientists and managers was blamed for the failure of conservation efforts for the Iberian lynx (Palomares *et al.*, 2011).

To build trust, a modeller should demonstrate their professional credibility and that of their modelling technique (Moser & Dilling, 2004). Effective communication at the early stages of a project is crucial. Investing time in frequent personal contact, such as face-to-face meetings, telephone calls and emails, will help modellers foster interpersonal ties (*Practical solution 5i*; Gibbons *et al.*, 2008; Janse, 2008). During such interactions, modellers should demonstrate their professional candour, an awareness of political sensitivities, the relevance of their model to the decision context and a willingness to change and adapt their approach to a problem (Gibbons *et al.*, 2008; Lusiana *et al.*, 2011). In particular, a modeller should not allow their values to influence the essential objectivity of their work (Krueger *et al.*, 2012). Such honest brokering is crucial for modellers to build and maintain trust with decision-makers (Pielke, 2007), but can be very challenging as modellers who work closely with decision-makers are bound to form value judgments about the decisions in which they are involved.

As we have mentioned, simply involving participants in the decision-making process will not guarantee success, nor will it guarantee trust in modellers. To build trust, modellers should carefully address the following three perceptions: (1) participants' perception—that participant involvement is merely a token gesture (Voinov & Bousquet, 2010), (2) experts' and decision-makers' perception—'lay' stakeholder opinions are untrustworthy and undermine the scientific credibility of management decisions and should not be given equal weight to 'expert' views (Treffny & Beilin, 2011), and (3) decision-makers' perception—participation of external stakeholders may delay or even halt a decision (Berghöfer, 2007). Trust between participants and modellers can be deepened by addressing such perceptions directly and openly and by engaging participants in active group decision-making where genuine opportunities for involvement and collaboration are promoted (*Practical solution 5ii*; Sultana & Abeyasekera, 2008; Eden, 2011). Finally, trust can be deepened between modellers and the wider community (those not actively involved in the decision-making process), by actively communicating the outcomes of the decision-making process (*Practical solution 5iii*; Arvai & Froschauer, 2010).

By maintaining effective interactions and using models suitable for the decision context, modellers can begin to gain trust from participants. Once trust is established, modellers will be in a much better position to dispel many of the common objections to models (Objections 1–9).

CONCLUSION

In this article, we have provided practical solutions for modellers to help improve the effectiveness and relevance of their work in conservation decision-making. We challenge modellers to view their contribution to decision-making as only one of many tools for decision support. We reiterate the importance of using a SDM framework to guide good modelling practice and to ensure that models incorporate a deep understanding of the decision context. We highlight a variety of modelling techniques that can be used to support decision-making and encourage modellers to select models that are both relevant to the decision context and that will engage participants with varying levels of technical experience. We emphasize the importance of participatory decision-making, in which decision-makers, stakeholders and experts are involved in all stages of the modelling process. Involvement of participants in model building will promote a clearer collective understanding of a problem and can improve the knowledge-base and social acceptance of decisions and facilitate better environmental outcomes. Finally, we suggest modellers develop skills in communication and trust-building to develop rapport with participants and anticipate and create opportunities to dispel common objections to using models in conservation decision-making.

The practical solutions outlined here represent a vision for the use of models in an applied context. We hope that our recommendations help broaden the use of models, forging deeper and more appropriate linkages between science and management for the improvement of conservation decision-making.

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