The Delphi technique in ecology and biological conservation: applications and guidelines

Nibedita Mukherjee[1,2,3*], Jean Hugé[3,4], William J. Sutherland[1], Jeffrey McNeill[5], Maarten Van Opstal[3,6,7], Farid Dahdouh-Guebas[2,3,†] and Nico Koedam[2,†]

[1]*Conservation Science Group, Department of Zoology, University of Cambridge, Cambridge CB2 3EJ, UK;* [2]*Plant Biology & Nature Management, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium;* [3]*Laboratory of Systems Ecology and Resource Management, Université Libre de Bruxelles, CP 264/1, Avenue F.D. Roosevelt 50, 1050 Brussels, Belgium;* [4]*Centre for Sustainable Development, Ghent University, Poel 16, 9000 Gent, Belgium;* [5]*School of People, Environment and Planning, Massey University, Private Bag 11222, Palmerston North, New Zealand;* [6]*Center of Cultural Anthropology, Université Libre de Bruxelles, CP 124, Avenue F.D, Roosevelt 50,1050 Brussels, Belgium; and* [7]*Public Health Department, Vrije Universiteit Brussel, Laarbeeklaan 103, 1090 Brussels, Belgium*

Summary

1. Many areas of science, including conservation and environmental management, regularly require engaging stakeholders or experts to produce consensus or technical inputs. The Delphi technique is an iterative and anonymous participatory method used for gathering and evaluating such expert-based knowledge.

2. We outline the methodology of the Delphi technique and provide a taxonomy of its main variants. In addition, we refine the technique by providing suggestions to address common limitations (e.g. time consumption, attrition rate) in order to make the method more suitable for application in ecology and conservation.

3. A comprehensive search for studies that have applied the Delphi technique in conservation and environmental management resulted in 36 papers. The Delphi technique has been applied to a range of issues, including developing decision support systems and predicting ecological impacts of climate change.

4. The papers reviewed suggest that the Delphi technique is an efficient, inclusive, systematic and structured approach that can be used to address complex issues. A major strength compared to other group-based techniques is the reduced influence of social pressures among respondents.

5. The Delphi technique is relatively little used and seems undervalued. Given its wide range of possible applications, it could be applied more widely in evaluating evidence and providing expert judgments.

Key-words: conservation, expert, management support, modelling, participatory approach, policy, scenarios, the Delphi technique

Introduction

The Delphi technique is a method used for enabling a group of individuals to collectively address a complex problem through a structured group communication process (Hasson, Keeney & McKenna 2000). The Delphi technique comprises two or more rounds of structured questionnaires, each followed by aggregation of responses and anonymous feedback to the participants (usually experts). Named after the ancient Greek oracle, the Delphi technique originated in USA in the 1950s as a predictive tool for the military (Dalkey & Helmer 1963). In the last 60 years, the Delphi technique has evolved considerably and is considered particularly suitable for addressing multifaceted issues, especially when information is limited or conflicting (O'Faircheallaigh 2010; Martin *et al.* 2012; McBride *et al.* 2012) or for combining different types of evidence (Sutherland *et al.* 2013). The Delphi technique is an established method in

a range of disciplines, such as medicine (Sinha, Smyth & Williamson 2011), nursing (Hasson, Keeney & McKenna 2000), social policy (Adler & Ziglio 1996), tourism (Donohoe & Needham 2009) and sustainability science (Hugé *et al.* 2010). A preliminary search for the term 'Delphi technique' in the Web of Science resulted in 529 documents for nursing, 484 for medicine, 303 for tourism, 694 for policy and 772 for economics. In sharp contrast, the Delphi technique appears relatively little used in ecology (five documents) or conservation (22), even though it may be well suited particularly for dealing with biodiversity management issues that are equally complex and involve multiple stakeholders and trade-offs (Hirsch *et al.* 2011; McShane *et al.* 2011; Sutherland *et al.* 2011; Redpath *et al.* 2013).

To our knowledge, there are no readily available guidelines for the application of the Delphi technique to ecological and conservation issues as opposed to other techniques (see Tables 1 and 2), such as questionnaires, interviews or focus group discussions (White *et al.* 2005; Gill *et al.* 2008). Although this technique has been applied in ecology, for exam-

*Correspondence author. E-mail: nibedita.41282@gmail.com
†Co-last authors.

Table 1. Glossary of technical terms used in the paper

Term	Explanation
Bounded rationality	Decision-makers (irrespective of intelligence or experience) have to work under three main constraints: (i) limited or unreliable information, (ii) limited capacity of the human mind to evaluate and process information and (iii) limited time available to make a decision
Nominal Group technique (NGT)	NGT is a structured group technique used to gather consensus. Participants are asked to provide information to questions asked by a moderator. Then, the participants are asked to prioritize the ideas and suggestions of group members. It is also referred to as the *estimate, talk, estimate* technique
Participatory approach	Defined by Steyaert & Lisoir (2005) as one that 'advocates actively involving "the public" in decision-making processes, whereby the relevant "public" depends upon the topic being addressed'
Prediction markets (PM)	Participants in prediction markets spend points (or money) to change the estimate in their desired direction. PM is anonymous like the Delphi technique, but there is no interaction among participants who respond directly to the price signal. Participants buy shares when they perceive the current estimate to be too low and sell when they perceive it to be too high to their desired choice
Statistical aggregation (SA)	In SA, participants submit a single estimate or judgement, which is then statistically aggregated at the group level. Participants do not interact with each other or share information
Voting	Individuals vote for their preferred choice
Decision Delphi	A Delphi technique application aiming at structuring decision-making by contributing to the creation of the future in reality rather than aiming at predicting the future (Hasson & Keeney 2011)
Scenario Delphi	A Delphi technique application aiming at constructing future scenarios in which respondents are asked about their probable and preferable future (Hasson & Keeney 2011)
Policy Delphi	A Delphi technique application aiming at generating opposing views on policy and on potential resolutions (Hasson & Keeney 2011)
Argument Delphi	A Delphi technique application aiming at developing relevant arguments and at exposing underlying reasons for different opinions on a specific single issue (Hasson & Keeney 2011)

ple to fill in data gaps (Eycott, Marzano & Watts 2011), and aid in decision-making (Mehnen, Mose & Strijker 2013), there has been no synthesis of these applications to guide future use. To encourage the appropriate application of the technique, we seek to address the following objectives in this paper:

1. Outline the process of the Delphi technique and classify the different variants.
2. Review the use of the Delphi technique in ecology and conservation.
3. Compare the Delphi technique with other similar techniques.
4. Discuss the limitations of the Delphi technique.
5. Suggest guidelines for refining the technique.

To address these objectives, we reviewed the literature on the Delphi technique in ecology and conservation. We used the keywords 'Delphi', 'Delphi technique', Delphi method' with 'conservation biology', 'biodiversity', 'biodiversity management', 'conservation' and 'biological conservation' in a search query within the ISI Web of Knowledge data base (http://apps.webofknowledge.com), Google and Google Scholar from 1955 to 2014 (as of 14th May 2013). The initial search included a range of document types (particularly from Google), from which we removed citations, patents and reports. We selected only peer-reviewed articles that had mentioned the Delphi technique in either ecology or conservation. This resulted in over 350 articles. From these, we read the papers in detail and selected those studies that had specifically applied the Delphi technique in biodiversity management or conservation biology. This resulted in 36 peer-reviewed articles (Table S1 in the Supporting Information). Applications of the Delphi

technique in the grey literature (e.g. policy documents and non-governmental organization reports) or documents in other languages are beyond the scope of this study.

The Delphi technique

The Delphi technique is a structured, anonymous and iterative survey of a panel of 'experts' or participants. It can be used (although not limited) to (i) generate consensus on controversial issues (e.g. in situations where there might be strongly polarized opinions) that are difficult to resolve in face-to-face settings, such as focus group discussions (Lemieux & Scott 2011); (ii) explore, or expose, assumptions or information leading to divergent judgments (Turoff 1970); (iii) fill in data gaps or validate models through experience of the participants, (e.g. O'Neill *et al.* 2008; Ochoa-Gaona *et al.* 2010); (iv) address complex issues that require pooling of inputs from different disciplines or geographic locations within limited time; and (v) formulate or evaluate policies (MacMillan & Marshall 2006; Orsi, Geneletti & Newton 2011). The structure of the Delphi technique allows a wide range of adaptations to suit the needs of the problem or question being addressed and facilitates knowledge exchange (Hasson & Keeney 2011). For instance, it can be used to seek or address dissenting views, particularly where complex socio-economic and ecological values are involved (see Argument Delphi below). Experts and non-experts can both share the same intellectual space and contribute to participatory decision-making on a common platform (Crabbe *et al.* 2010; Swor & Canter 2011).

Additionally, the Delphi technique is sufficiently flexible to be applied at vastly different scales. For example, it has been

Table 2. Comparison of the Delphi technique to other commonly used techniques in group decision-making. Anon, Anonymous. + means that the method is effective for achieving the set objective, – means that the method is not suited for achieving the set objectives. The Delphi technique combines the benefits of group discussion, iterations and anonymity without the added constraint of geographic proximity.

	Method	Possibility of iterations	Impacted by social pressure	Suitable for conflict issues	Possibility of anon. discussion	Possibility of voting	Possibility of anon. voting	Requirement of geographic proximity	Requirement of skilled facilitator	Requirement of expert judgment	References
No discussion possible	Questionnaire	–	–	–	–	+	–	+	–	–	White *et al.* (2005)
	Statistical Aggregation	–	–	–	–	–	–	–	–	–	Kerr & Tindale (2011)
	Confidential voting	–	–	+	–	+	+	–	–	–	Redpath *et al.* (2004)
	Public Voting	–	+	–	–	+	–	–	–	–	Burgman *et al.* (2014)
	Prediction markets	+	–	+	–	–	–	–	–	–	Kerr & Tindale (2011)
Discussion possible	Focus group discussion	–	+	–	–	+	–	+	+	+	Fischer & Young (2007)
	Nominal Group technique	+	+	–	–	+	–	+	+	+	Sutherland (2006)
	Delphi technique	+	–	+	+	+	+	–	+	+	Hasson, Keeney & McKenna (2000)

used to study issues ranging from the local scale, such as the triangle region in North Carolina (Hess & King 2002), to a global assessment, such as the UN water development report that involved representatives from around 18 countries (UNESCO 2009).

The Delphi technique's anonymous nature aids in addressing a range of social pressures that affect group-based approaches. The best recognized social pressures are as follows:

1. *Groupthink*: individuals in a group tend to seek concurrence among the group at the expense of independent critical thinking. This results in poor decisions as members tend to avoid creating disunity and support the decisions taken by the majority or the perceived leader of the group. The desire or pressure to be accepted as a good group member leads to acceptance of the majority solution that may not be logical or scientifically sound (Janis 1971). For instance, Janis (1971) noted that, in the case of the Vietnam War, US president Lyndon B Johnson's in-group kept escalating the war in order to retain group conformity in the face of repeated setbacks and failures.

2. *Halo effect*: decisions or perceptions are coloured by perceptions of attributes that are totally unrelated to the topic (Nisbett & Wilson 1977). For instance, when evaluating an essay, male college students ranked a poor quality essay written by an attractive woman higher than the better quality essay written by an unattractive woman (Landy & Sigall 1974).

3. *Egocentrism*: individuals tend to preferentially rate their own opinion higher than that of others (Yaniv & Kleinberger 2000).

4. *Dominance*: members in a group tend to support ideas of dominant individuals. Dominant individuals are usually those with (perceived) higher status, greater persuasive ability or higher persistence, yet none of these attributes are related to better problem solving ability (Maier 1967).

The consensus-based Delphi technique (the classical approach), broadly comprises the six steps given below (Fig. 1). The variations to this approach are discussed in the section on categorizations of the Delphi technique. A detailed description of the technique can be found in Hasson, Keeney & McKenna (2000); Powell (2003); Landeta (2006); Hasson & Keeney (2011).

PREPARATION OF FIRST ROUND OF THE QUESTIONNAIRE

The first round questionnaire may be unstructured (i.e. with open-ended questions to gather opinions) so that participants can elaborate on and discuss the issues being addressed (Powell 2003). Semi-structured questionnaires drawing from evidence based on published literature could also be used (Powell 2003). Examples of first round questionnaires can be found in Clark *et al.* (2006) and Gomez-Zamalloa, Caparros & Ayanz (2011). Depending on the question type, subsequent rounds may involve ranking of the responses obtained in the first round (e.g. Gomez-Zamalloa, Caparros & Ayanz 2011).

1 Prepare the first round of the questionnaire
- Define clear objectives
- Use a pilot round with independent experts
- Check facilitator skills
- Set consensus threshold

2 Select and invite respondents
- Define selection criteria
- Choose respondents who have a direct interest in the topic/issue and an outgroup

3 Collect and analyse the responses

4 Provide feedback to the participants
- Allow dissenting individuals to explain their views
- Use content analysis or coding techniques for qualitative responses
- Provide statistical summaries for quantitative responses

6 Iterate till consensus is reached

5 Prepare, distribute and analyse the subsequent round of questionnaire
- Limit time lapsed between rounds and number of rounds

Fig. 1. Flowchart of the steps involved in the Delphi technique. Guidelines to avoid some of the common limitations of the technique are also highlighted (see section on guidelines).

SELECTION AND INVITATION OF A PANEL OF RESPONDENTS

Initially, the Delphi technique was designed for 'experts', but it is increasingly becoming more inclusive (Rowe & Wright 2011). For example, Hussler, Muller & Rondé (2011) recommend including participants from a greater diversity of backgrounds. The breadth of participants (e.g. practitioners, conservationists, non-governmental organizations, policymakers and indigenous groups) can provide a wide range of perspectives and minimize bias arising due to self-interest (or information bias) by any particular group in the topic under consideration. The respondent panel size is not required to be a statistically representative sample since the panel representativeness is judged based on the respondents' attributes (Powell 2003). Powell (2003) and Landeta (1999) suggest that the number of participants should be between seven and fifty or over. In our review, the number of participants (mostly experts) ranged from two to 184, while 19 out of 31 studies that had mentioned the number of respondents, had fewer than 20 respondents for all the rounds (Fig. S1).

COLLECTION AND ANALYSIS OF THE COMPLETED QUESTIONNAIRE FOR THE FIRST ROUND

The responses are collated and analysed using qualitative or quantitative measures (Tapio *et al.* 2011). For qualitative questions, the statements are categorized and reduced to major themes (e.g. via content analysis or coding techniques), while for quantitative responses, statistical summaries are generated, for example central tendencies (mean, median, mode values) and levels of dispersion (standard deviation and interquartile range). Deciding on the level of consensus desired for the

process depends on context, as discussed in the guidelines (Guidelines for specific components of the Delphi technique) below. The results are compiled into a report, which is used in the next step as feedback. Of the 17 studies that provided quantitative details of the feedback given to the participants, ten provided the mean, seven provided the median and six studies reported the standard deviation.

FEEDBACK ON THE RESPONSES GATHERED FROM ALL PARTICIPANTS

Each participant is provided both with the collective opinion (e.g. through the statistical summary) and a reminder of their own response for each item in the questionnaire. This allows individual participants to evaluate their responses in the light of the group responses. Each respondent may then use this information to explain their opinions or reconsider them in subsequent rounds. In an experiment, Rowe, Wright & McColl (2005) showed that the proportion of correct responses increases over Delphi rounds when feedback (statistical summaries or written rationales) is provided. This was not the case for 'control iterations' (i.e. without feedback) illustrating that respondents learnt from others during the iterations.

PREPARATION AND ANALYSIS OF SECOND ROUND OF QUESTIONNAIRE

The collated responses of the first round are typically used to prepare a structured questionnaire used in the second round. Extra questions/topics may be added if they are suggested by the respondents in the first round of the Delphi technique. The second round questionnaire is administered only to respondents who participated in the first round. Respondents are

thereby self-selected from the second round onwards. Those responses that are qualitative could be analysed using ranking or rating methods (Powell 2003). A typical example of a ranking-based method is the Likert scale (Likert 1932), where participants are asked to rank their responses on a scale of 'one to five' where 'one' may indicate 'agree', while 'five' indicates 'disagree'.

ITERATION

The preparation of the questionnaire, analysis of responses and feedback to respondents are repeated in subsequent rounds until reaching either the desired level of consensus or the number of rounds (see Guidelines for specific components of the Delphi technique for consensus criterion). All participants can weigh dissenting views without being confronted by social pressures (see Comparison of the Delphi technique to other techniques below) and consensus typically increases from round to round. After the desired level of consensus or number of rounds (pre-determined cut-off) is reached, the respondents are shown the final report along with their individual responses. A larger number of rounds can make the process more time-consuming, leading to participant fatigue and a higher attrition rate (Powell 2003). Therefore, the number of rounds should be limited and adapted according to the time available, but at least two rounds are needed to provide feedback and allow respondents to revise their initial responses. Of the 30 studies in our review that mentioned the number of rounds, 12 used two rounds and 13 used three rounds, and the number of rounds ranged from one to four (Fig. S1).

Categorization of the Delphi technique

The Delphi technique can be classified into four categories relevant for ecology and conservation, following the classification scheme of Hasson & Keeney (2011): decision, scenario, policy and argument. These four categories and their uses are described in Fig. 2 and two examples of each of category are given in Table 3. The choice of the category of the Delphi technique depends heavily on the context and questions that need to be addressed. The categories are not mutually exclusive and can be combined depending upon the issue at hand.

DECISION DELPHI

Decision Delphi is primarily aimed at formulating, assisting or making decisions (Rauch 1979). Decision-making is a complex process and often not a linear one, due to interpersonal and psychological issues mediated by social pressures (see Comparison of the Delphi technique to other techniques below). Yet, given that most decision makers have bounded rationality (Table 1) (Simon 1984), we need to aggregate this knowledge for collective decision-making. In Decision Delphi, those with decision-making power can make decisions intended to achieve a desired conservation or management target with reduced bias. Decision Delphi could also be used to identify indicators to evaluate and prioritize aspects of biodiversity management, such as restoration efforts or ecosystem functioning.

SCENARIO DELPHI

Scenario Delphi is useful for exploring alternate scenarios where participants are asked to envision probable and preferable futures. It aims at eliciting alternative futures based on the participants' background and experience. Scenario Delphi can be of two types: explorative and predictive. In explorative scenario studies, the Delphi technique aims at capturing creative input, identifying future challenges or adaptation options to environmental change. In predictive
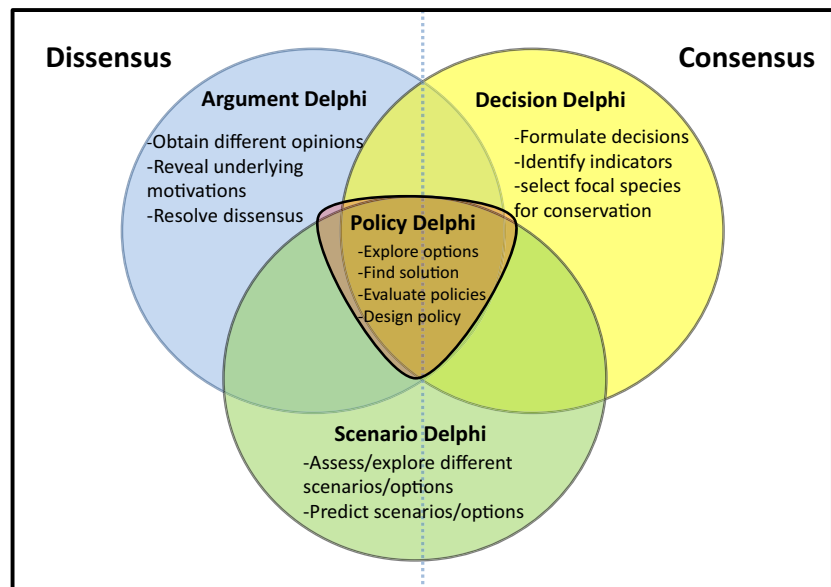
Fig. 2. A schematic representation of the four categories of the Delphi technique using consensus and dissensus as criteria to differentiate between the different types. Examples of key objectives that can be addressed by each category of the Delphi technique are indicated here as a first glance of the four categories. While decision Delphi is mostly consensus based, argument Delphi tends to lean towards dissensus. Scenario Delphi is more neutral in terms of consensus and is targeted more towards predictions. Policy Delphi is a subset of all the three above and draws equally from consensus and dissensus.

Table 3. Selection[1] of applications of the Delphi technique in ecology and conservation

Type of Delphi	Geographic location/country	Number of rounds	Number of participants	Objective and output of the Delphi technique	Pros and cons noted by the authors of the original study	References
Decision	USA	3	22 (1), 20 (2), 19 (3)	Develop a plan for wildlife conservation. Six landscape types and nine focal species were identified by the experts.	Respondents could consider the questions for a prolonged period of time enabling a more considered decision. However, the authors found it labour intensive and time-consuming probably due to the use of paper questionnaires	Hess & King (2002)
Decision	Global	2	37 (1), 30 (2)	Design criteria and indicators for prioritization of restoration efforts. Eight criteria and 90 indicators were identified.	Helped in generating ideas from scratch. The study emphasized the applicability of the Delphi technique in combination with face-to-face meetings in facilitating better ecological restoration. However, the authors noted that the knowledge of the experts may be limited or flawed	Orsi, Geneletti & Newton (2011)
Scenario	Arctic region	3	10 (all)	Quantify the impacts of climate change on polar bear *Ursus maritimus* populations. The population size was predicted to vary between no change and a 70% decrease by 2050. Half of the experts project at least a 30% decrease	Useful as an expert-based approach in data poor situations. However, there were uncertainties within and between experts	O'Neill *et al.* (2008)
Scenario	Italy	2	46	Rank potential of different land cover types to provide ecosystem services. 46 experts from 10 Italian institutions, provided input for scenarios of spatial patterns of gains and losses in ecosystem services over a decade (1990–2000)	Experts provided assessment of a large number of ecosystem services by engaging experts from different backgrounds	Scolozzi, Morri & Santolini (2012)
Policy	European Union	2	35 (1), 32 (2)	Evaluate the impact of 15 years of forest certification in the European Union with respect to ecological, economic and social aspects. The impact of certification was found to be positive–neutral with respect to ecological aspects, positive–negative on the economic aspects, and positive–neutral on the social aspects	Useful in integration of diverse external factors in the evaluation process	Gomez-Zamalloa, Caparros & Ayanz (2011)
Policy	Canada	2	45 (1), 34 (2)	Identify and assess policy-relevant climate change adaptation options across the different management areas of a protected area agency (Ontario Parks). Delphi panel identified and appraised 165 adaptation options for protected area management	Effective in generation of ideas for policy formulation and neutral from social pressures (social status, loss of face, dominant personalities). Provided the opportunity to present innovative and controversial ideas	Lemieux & Scott (2011)
Argument	Global	3	8 (all)	Generate data on the forms of ecological reasoning and social norms that influence ecological science. The Delphi technique enabled the authors to provide a richer understanding of scientific objectivity and the contribution of values to it	Useful for complex issues and for generating debate	Wallington & Moore (2005)
Argument	Canada	3				Miller & Cuff (1986)

scenario studies, the Delphi technique aims to clarify judgments about forecasting (Nowack, Endrikat & Guenther 2011). Scenario Delphi (scenario thinking) can be useful for envisioning creative solutions to complex problems, such as climate change (Table 3).

POLICY DELPHI

Policy Delphi aims at eliciting the breadth of views relating to the policy under question and seeks to identify potential resolutions (Turoff 1970; Hasson & Keeney 2011). Policy Delphi focusses on obtaining both common and divergent opinions on policy issues, to identify priorities and potential solutions to policy problems (Donohoe & Needham 2009; Frewer *et al.* 2011). Policy Delphi is different from Decision Delphi since it does not focus on making one decision but rather on identifying various options (Fig. 2). Policy Delphi has been used to develop a range of public policies in several domains, for example for information and communication technology policy by Hilbert, Miles & Othmer (2009) and for agrifood policy development by Frewer *et al.* (2011). Policy Delphi is useful for generating innovative solutions to respond to complex socio-ecological challenges, such as climate change and sustainable development (examples in Table 3).

ARGUMENT DELPHI

Unlike the classical consensus-based Delphi technique, Argument Delphi aims to explore dissensus rather than relying on creating a single consensus view (Tapio 2002; Steinert 2009). Argument Delphi is useful for exposing underlying reasons for divergent opinions on an issue (Kuusi 1999). It delves deeper into the motivations underpinning the participant's opinions and is thereby useful for generating new opinions. Such dissensus-based applications of Argument Delphi may be useful in addressing conflict issues, questioning current paradigms in ecological thinking, stimulating debate and formulating new ideas about biodiversity management.

Applications of the Delphi technique

In this section, we describe the range of contexts where this technique has been applied in ecology and conservation, using examples from the review.

AID DECISION-MAKING

Hess & King (2002) used the Delphi technique as an expert-based approach to develop a plan for wildlife conservation. The Delphi technique was used to identify focal species for conservation in a suburbanizing region in North America (North Carolina, USA). Experts identified six landscape types and nine focal species through this method. The Delphi technique has also been used where empirical data were lacking, for example in the context of endangered wood grouse, *Tetrao*

Table 3. (continued)

Type of Delphi	Geographic location/country	Number of rounds	Number of participants	Objective and output of the Delphi technique	Pros and cons noted by the authors of the original study	References
			41 (1), 24 (2), 26 (3)	Mediate conflict over the spruce budworm issue in New Brunswick, Canada. Both factions were able to identify significant psychosocial components of the environmental dispute and suggest solutions	The Delphi approach brought in structure and trust to the mediation process	

The applications of the four different types of the Delphi technique are illustrated with two examples of each type. The number mentioned in brackets in the 4th column is the corresponding round number. [†]The studies that provided complete information (number of participants for each round, location, objective, output, merits and demerits of using the Delphi technique) are shown here. The complete list of all the 36 studies can be found in Table S1.

urogallus, where it was used to develop a model for improving the habitat (MacMillan & Marshall 2006). Similarly, the Delphi technique was used to estimate the carrying capacity of the habitat of the threatened northern spotted owl (Murphy & Noon 1992). Gobbi *et al.* (2012) used the Delphi technique to identify 229 invertebrate species that were either endangered or of 'mandatory conservation interest' for which detailed empirical data were lacking. Ochoa-Gaona *et al.* (2010) used the Delphi technique to validate a model for measuring the ecological condition of tropical forests based on the participants' (researchers') extensive field experience. In addition, the Delphi technique has been used to provide 'local' adjustment to models, which are otherwise difficult to attain (Scolozzi, Morri & Santolini 2012).

The Delphi technique can be also used in combination with other techniques, for example Crabbe *et al.* (2010) used it along with the Nominal Group technique (described in Table 1) to develop personal action plans for improving the sustainability of the marine protected areas in the Meso-American Barrier Reef System. Use of the Delphi technique helped share information and integrate ideas, between local non-governmental organizations and a government officer (Crabbe *et al.* 2010).

Mehnen, Mose & Strijker (2013) and De Urioste-Stone, McLaughlin & Sanyal (2006) used it to obtain information about governance and to understand the co-management of protected areas. Such applications suggest that the Delphi technique is particularly relevant for assisting participatory management (Table 1) of conserved landscapes and greater inclusion of the public in decision-making. Mehnen, Mose & Strijker (2013) observed that one of the main strengths of using the Delphi technique was the resulting clarification of vague concepts.

AID CONSERVATION POLICY

The Delphi technique is particularly useful for situations where there are 'conflict of interests. For instance, Policy Delphi was effective in generation of ideas for policy formulation and useful in dealing with issues where there was dissensus or disagreement (Lemieux & Scott 2011). In addition, the Delphi technique documents were critical in a legal challenge in conservation by Clark *et al.* (2006), who had used the Delphi technique to assign legal protection status of 283 bird species in New Jersey. The survey documents were used as evidence in resolving species status designations during legal disputes.

The Delphi technique has also been used to evaluate policy (Choi & Sirakaya 2006; Swor & Canter 2011) or the impact of policies. For example, Gomez-Zamalloa, Caparros & Ayanz (2011) used the Delphi technique to evaluate the ecological, economic and social impact of 15 years of forest certification in the European Union, and it could be used as a key stage in assessments, such as those of the International Panel on Climate Change (Sutherland 2013).

IDENTIFY INDICATORS

Oliver (2002) used the Delphi technique to generate indicators to assess vegetation condition in Australia, while Eycott, Marzano & Watts (2011) applied this technique to identify parameters for indicators of functional connectivity between landscapes in the UK. The Delphi technique has been used in combination with ecological modelling, such as in ranking the relative resistance of a range of factors to giant panda (*Ailuropoda melanoleuca*) movement within its habitat in the Minshan mountains in China Shen *et al.* (2008).

GENERATE NOVEL SOLUTIONS AND ADVANCE OUR CURRENT UNDERSTANDING

Orsi, Geneletti & Newton (2011) noted that the Delphi technique was useful in generating novel ideas. Argument Delphi is well suited to challenge current thinking and progress our contemporary understanding by encouraging scientific debate about existing theories. The Delphi technique could therefore aid in developing new concepts and solutions (Wallington & Moore 2005; Moore *et al.* 2009). MacMillan & Marshall (2006) stated that the Delphi process allowed for sufficient debate and integrated dissenting views. De Lange *et al.* (2010) observed that anonymity in the Delphi technique allows true opinion to emerge with less pressure to conform to social pressures.

Comparison of the Delphi technique to other techniques

The Delphi technique is particularly suitable for complex issues where the outcome is not dependent on the sample size of the respondents, but rather on the different perspectives and expertise of respondents and their indirect group interactions. The Delphi technique is thereby best compared to approaches commonly used in group decision-making such as nominal group technique, focus group discussions, prediction markets or statistical aggregation (Table 1).

Table 2 compares the Delphi technique with other techniques aimed at achieving consensus or supporting decisions. Such methods can be broadly divided into two categories: those that provide the possibility of discussion or indirect interaction among participants (e.g. nominal group technique, focus group discussions, the Delphi technique) and others that do not (e.g. questionnaires, voting, prediction markets and statistical aggregation). The choice of the method should be based on the level of inputs or participation that the situation requires. In situations where group discussions or decisions are not needed, questionnaires or statistical aggregation may be adequate. Moreover, methods that do not require participants to be brought physically together (e.g. statistical aggregation or the Delphi technique) are usually more efficient in terms of time and cost.

Focus group discussions and nominal group technique may be useful where face-to-face interactions are needed and/or for generating opinions through discussion and group interactions. Iterative techniques (e.g. nominal group technique or the Delphi technique) further refine the process by providing the possibility for reconsideration or revision of initial responses in the light of the comments of others in the group (Sutherland *et al.* 2011) (Table 2). Unlike single iteration methods, such as interviews or structured group methods, which do not provide individual feedback (e.g. nominal group technique), the iterative nature of the Delphi technique, combined with the feedback process, ensures more credibility to the final outcome by allowing experts to re-assess and change their responses (Eycott, Marzano & Watts 2011). In addition, unlike face-to face discussions in focus group discussions, the written feedback process of the Delphi technique makes the procedure retraceable and transparent and therefore useful in legal challenges (Clark *et al.* 2006; MacMillan & Marshall 2006; Geneletti 2008).

In contrast to focus group discussions and nominal group technique, the Delphi technique is relatively free from social pressures due to its anonymous nature as explained above (Hess & King 2002; Spenceley 2008; Martin *et al.* 2012) (Table 2). Ayton, Ferrell & Stewart (1999) note that removing the link between the source of the opinion and the opinion itself (i) motivates respondents to think deeply into the issue in a dispassionate manner and (ii) minimizes the halo effect. Experts can express their opinion freely without the fear of 'losing face' or fear of repercussion from controversial opinions (Powell 2003; McBride *et al.* 2012). Anonymity retains focus on the problem or the issue at hand rather than distracting attention towards personal biases or agendas. The Delphi technique thereby brings in more neutrality and objectivity into the judgment process than other group facilitation techniques, for example nominal group technique or focus group discussions (Ayton, Ferrell & Stewart 1999). This feature is important when several experts from diverse fields in conservation or ecology are engaged in decision-making and where there may be conflict of interest or opinion between the stakeholders (De Lange *et al.* 2010; Kuhnert, Martin & Griffiths 2010; Lemieux & Scott 2011).

From a practical point of view, conducting the Delphi technique is efficient in terms of both time and costs even though preparation for the technique may require considerable time (see limitations mentioned below). The Delphi technique permits collecting information from experts who are not able to be brought together physically because of wide geographic distribution or different time zones (as opposed to focus group discussions or nominal group technique) (Mehnen, Mose & Strijker 2013). These attributes make the Delphi technique especially relevant and suitable for developing countries, where constrained budgets limit consultation of experts or face-to-face meetings (Rowe & Wright 2011). As a further technological improvement, real-time Delphi technique using Web-based tools can be used within a short time frame and so avoiding meeting costs.

Limitations of the Delphi technique

The Delphi technique may not be appropriate for all situations. For instance, the Delphi technique is neither a substitute for quantitative data, such as biomass, species diversity or tree height, when such data are already available, nor should the Delphi technique be used as an excuse to not collect such quantitative data if the opportunity exists. In such situations, the Delphi technique can be an excellent complementary method (e.g. to identify potential habitat preferences of species) but not more.

One common methodological problem identified in the literature is the lack of accountability of responses due to anonymity. This could lead to incorrect responses or lapse of judgement since the respondents may feel that they do not need to be careful in making responses (Powell 2003; Landeta 2006). However, this risk can be reduced by offering the participants the choice to forgo anonymity at the end of the Delphi process. In addition, in iterative processes, a combination of anonymous discussion followed by a face-to-face meeting is often beneficial to combine the strengths of the nominal group technique and the Delphi technique (Hutchings & Raine 2006).

The focus on consensus in the consensus-based Delphi technique may lead to a diluted version of the best opinion as disinterested respondents start to conform inadvertently to the majority view. For instance, Rowe, Wright & McColl (2005) showed that even an incorrect majority opinion exerts a considerable opinion pull on the minority opinion, irrespective of the type of feedback provided.

Furthermore, lack of care and planning in implementing the Delphi technique can lead to problems. These include problems identifying the level of consensus or forced consensus (where dissenting individuals feel marginalized and leave the process or give in to the dominant view), inappropriate selection of participants, poor explanation of the technique (Powell 2003), inadequately formulated questions, insufficient/biased analysis of results and high attrition rate between rounds (Landeta 2006).

Additionally, the iterative nature demands considerable effort from the respondents as well as the team or individual facilitating the Delphi technique. Hence, it may not be appropriate where the respondent group size is very large (several hundreds), for example in public voting. In a strict Delphi process, there is no scope for direct interaction, debate or discussion among respondents due to controlled feedback (Landeta 2006), which could also lead to frustration among participants in the case of a dissensus.

The Delphi technique was initially designed specifically for making predictions with no possibility for objective verification at the time when the decision was being made. Over the years, the application of the technique for predictions has met with much criticism (Woudenberg 1991). However, predictions currently form only a small fraction of the applications of the Delphi technique (also see guidelines). Moreover, in a long-term study (30 years) on the accuracy of predictions based on the Delphi technique, it

was found that in 14 out of 18 scenarios, the predictions of the Delphi technique panellists were accurate *a posteriori* (Parente & Anderson-Parente 2011).

Guidelines for specific components of the Delphi technique

Some common limitations of the technique can be addressed by using the guidelines suggested below.

SELECTION AND ENGAGEMENT OF RESPONDENTS

The selection of respondents should be based upon objective (if possible, quantifiable) criteria defined prior to the study (e.g. Mukherjee *et al.* 2014b). The criteria depend on the aim of conducting the Delphi technique (e.g. to crystallize abstract concepts or identify indicators). Examples of criteria include (i) years of experience, (ii) number of peer-reviewed publications in international journals, (iii) direct involvement in the issue/problem, (iv) engagement with relevant organizations and (iv) indigenous knowledge [e.g. Rist & Dahdouh-Guebas (2006)].

However, qualifications, experience or perceived status of experts is often poor indicators of expert performance (Burgman *et al.* 2011b). Discussion and cross-examination of ideas within a structured process, may be useful in improving the decision outcomes. This is possible in a modified Delphi technique-based approach (Burgman *et al.* 2011b). In addition, the easiest way to improve participant engagement would be to improve the design process and eliminate inadequately formulated questions by (i) defining clear problem objectives, (ii) checking if there is relevant knowledge (for fact-based Delphi process), (iii) identify and remove linguistic ambiguity by piloting the questionnaire with at least two independent experts (as done in the case of Mukherjee *et al.* 2014a). Using parallel forms (e.g. changing the order or the wording of the questionnaire and checking if this affects the responses) may also be useful (Hasson & Keeney 2011). Further guidelines suggested by (Burgman *et al.* 2011a) include broadening the set of expertise involved in deliberations as explained in participant selection above (see Table 1 in Glass, Scott & Price 2013 as an example) and testing and training of experts to make them more accountable.

CONSENSUS CRITERION

A recent review identified 15 types of indicators to measure consensus (von der Gracht 2012). Criteria for consensus and quantitative indices used to measure it where applicable (e.g. Meijering, Kampen & Tobi 2013) should be clearly stated before conducting the Delphi technique (Keeney, Hasson & McKenna 2006). Diamond *et al.* (2014) report that out of 98 consensus-based Delphi studies, the most common definition for consensus was percentage agreement (usually 75% as the median threshold). Respondents holding the minority view may unconsciously choose to align their responses with the majority view leading to a forced consensus (Rowe, Wright &

McColl 2005). In order to address forced consensus, we recommend (i) better communication of dissenting opinions between rounds by the facilitator (e.g. by allowing the dissenting individuals to explain their views), (ii) recognition that dissensus is also a valid outcome that may be more important than consensus (indicating where further research needs to be focused to resolve differences empirically) and (iii) acceptance of variability of opinion.

TIME CONSUMPTION AND ATTRITION RATE

The Delphi technique is often reported to be time-consuming with high dropouts between rounds (e.g. as noted in Benitez-Capistros, Hugé & Koedam 2014). The facilitator therefore has to make a deliberate choice concerning the trade-off between the number of iterations (depth of deliberation/reconsideration possible) and the time demands placed on the participants. Six measures may help address these two problems: (i) favour online approaches over paper-based survey forms (Frewer *et al.* 2011; Rowe & Wright 2011), (ii) choose respondents who have a direct interest in the topic/issue, (iii) conduct a pilot survey to check for clarity (Rowe & Wright 2011), (iv) use a smaller number of questions and rounds, (v) provide adequate explanation between rounds to hold the interest of the respondents and (vi) limit lapsed time between rounds so that respondents spend less time in re-acquainting themselves with the process and the questions.

PROBLEM OF EVALUATING OUTCOMES

The difficulty of evaluating outcomes can be partially addressed at best. We recommend (i) complementing the Delphi results with published literature or combining it with other tools, such as modelling (if possible), (ii) undertaking sensitivity analysis as part of the Delphi technique process (explore sensitivity of a decision to best, worst and most likely scenarios) (De Brucker, Macharis & Verbeke 2013) and (iii) include an 'out-group' if possible, that is a person or persons who are not part of that (research) community but may have sound opinions to challenge the expert biases that might have crept into that domain of research.

FACILITATOR SKILLS

The design process of the Delphi technique would substantially benefit from an estimation of the facilitator's attributes necessary to undertake the rounds successfully. This should be a part of the early-stage decision about whether the team is capable of conducting the Delphi technique. The required facilitator skills include credibility/impartiality to participants, knowledge of topic, analytical and review skills and organizational abilities.

Conclusions

Participatory techniques, such as the Delphi technique, provide a valuable interface of dialogue between technical

experts, decision-makers and the public, especially when conflicting interests need to be addressed simultaneously. The Delphi technique is not only a useful method for generating consensus (Hasson & Keeney 2011), but also equally suitable for challenging current paradigms in ecology and conservation science (through dissensus-based Delphi technique), identifying future priorities or stimulating debate where conflicting issues need to be addressed, such as human–wildlife conflict issues. Interactivity embodied in the 'learning from others' approach in the Delphi technique is useful for addressing conflicts and forming better policies for conservation in the future (Spenceley 2008; Moreno, Morales & Traba 2010).

The Delphi technique is indeed most suited where decisions or views cannot (solely) be based on established facts, but demand interpreting complex and conflicting information. It is also highly useful for topics with a large degree of uncertainty or for issues that are strongly influenced by societal debate and require an unpressured approach by experts in anonymity. Based on the evidence of versatility and wide range of applications of the Delphi technique presented in this study, we hope that it will be more readily accepted and utilized in ecology and conservation in the future and help in bridging the gap between science and policy.

Acknowledgements

Data accessibility

The secondary data used in this paper are available in the supplementary material.

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Table S1. Summary of the thirty six studies in which the Delphi technique was applied to issues relating to biodiversity and conservation. (NM implies 'not mentioned', N/A implies 'not applicable'.)

Fig. S1. Number of rounds of the Delphi technique used in published studies in ecology and conservation.