Integration of social and ecological sciences for natural resource decision making: challenges and opportunities

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Abstract

The last 25 years have witnessed growing recognition that natural resource management decisions depend as much on understanding humans and their social interactions as on understanding the interactions between non-human organisms and their environment. Decision science provides a framework for integrating ecological and social factors into a decision, but challenges to integration remain. The decision-analytic framework elicits values and preferences to help articulate objectives, and then evaluates the outcomes of alternative management actions to achieve these objectives. Integrating social science into these steps can be hindered by failing to include social scientists as more than stakeholder-process facilitators, assuming that specific decision-analytic skills are commonplace for social scientists, misperceptions of social data as inherently qualitative, timescale mismatches for iterating through decision analysis and collecting relevant social data, difficulties in predicting human behavior, and failures of institutions to recognize the importance of this integration. We engage these challenges, and suggest solutions to them, helping move forward the integration of social and biological/ecological knowledge and considerations in decision-making.

Key words: adaptive management; multi-objective decision analysis; decision science; natural resources; social science; structured decision making

Introduction

Decision making for natural resource management requires understanding both the ecological and social aspects of a decision (Bennett et al. 2017). Despite the recognition that effective natural resource management must integrate the social and ecological sciences (Decker et al. 1992), such integration in practice is relatively rare. The increasing use of decision science, including decision analysis (i.e., “structured decision making” and “adaptive management”; Gregory and Keeney 2002, Gregory et al. 2012), in natural resource management offers possibilities for integrating social and ecological sciences into decision making. Despite this, challenges remain. In decision analysis, values (i.e., preferences) are elicited to articulate objectives of the decision maker(s), and the outcomes of alternative management actions are evaluated relative to each other based on their predicted ability to achieve objectives. Stakeholder values guide the process (Keeney 1992, 1996) and help clarify how decision maker priorities relate to stakeholder preferences. Thus, an accurate, detailed understanding of stakeholder values is vital to the integrity of the entire decision process; all the ecological and biological data one can amass to feed the process will not make up for poor understanding of stakeholder values. This means data from *social science* research—not anecdote, intuition, facilitator, or special interest preferences—specific to the decision context are needed to support decision analysis. Lacking that, the process could go off track, seemingly supporting decisions that ultimately are unlikely to be socially accepted, potentially hindering conservation. With such consequences in mind, we describe the use of multi-objective decision analysis in natural resource management, outline several challenges related to incorporating social science into decision analysis, provide suggestions for overcoming these challenges, and identify avenues for future research.

Use of Decision Science in Natural Resource Management

Decision analysis is a quantitative method used in decision science, first developed for incorporating economic uncertainty into business decision making (Raiffa 1968), and is a framework for quantitatively evaluating decision options (Peterman and Peters 1998). The process of iterating through the steps of a decision can be applied to decisions that include ecological and social dimensions common in natural resource management (Peterman and Peters 1998). The steps of structured decision making include defining the problem, identifying relevant objectives, describing management actions that could achieve the objectives, predicting the consequences of each action on each objective, and evaluating tradeoffs among objectives (Figure 1; Hammond et al. 1999). We then refer to adaptive management, in the decision theoretic sense (McFadden et al. 2011), as a special case of structured decision making, in which repeated decisions are made to reduce uncertainty through learning by doing. Applications of decision analysis largely have focused on predicting the effects of management actions on ecological objectives (e.g., population size or harvest rates; Williams and Johnson 1995), often failing to consider, or only giving perfunctory thought to, social objectives.

Despite recent growth, the use of quantitative, structured approaches to inform fish and wildlife management decisions is still relatively uncommon (Runge et al. 2013, McGowan et al. 2015, Sells et al. 2016). Examples include using adaptive harvest management to manage waterfowl hunting pressure (Williams and Johnson 1995, Johnson et al. 2015), considering tradeoffs between salmon abundance and revenues from hydropower production (Failing et al. 2013), and managing bighorn sheep pneumonia epizootics (Sells et al. 2016). Substantive incorporation of social science theory and methods into these decisions is even less common. It is conceivable that not all decision science problems require integrating social considerations, but given the social context underlying natural resource management (Bennett et al. 2017) and the inherently political nature of fish and wildlife management, social considerations will always be a key component of a successful decision. That being said, decision analytic techniques can be useful for focusing on a single objective of a larger decision problem or on problems that are simply plagued by ecological uncertainty (e.g., adaptive management applications such as Gannon et al. 2013). However, care must be taken to ensure that social objectives are not being ignored. Here we focus on multi-objective decision problems that are common in natural resources management, in which ecological, economic, and social values are often at play (McDaniels et al. 2006).

Each step in the decision-analytic framework offers opportunities for social science to inform management decisions, including defining values, preferences, and objectives of stakeholders, quantifying those objectives, and making tradeoffs among them (Figure 1). We first explore a number of challenges associated with the integration of ecological and social sciences in multi-objective decision analysis and then discuss potential solutions.

Challenges for Integrating Social Science into Decision Analysis

1) Ecologists often lack familiarity and experience with social science

In fisheries and wildlife management, most examples of decision analysis that we are aware of have been led by ecologists rather than social scientists. Decision analysis in fish and wildlife management is in its infancy, and the ecological scientists who have attempted to incorporate social science into analyses are to be lauded for their efforts to pioneer decision analysis in this field. But lack of social science expertise in these early examples can become a research limitation. Ecologists may view social science as "common sense" compared to the technical complexity of ecology (Gregory and Keeney 2002). Ecologists—quite reasonably—

usually lack formal training in theories and methods of social science inquiry, yet without access to social scientists on their decision analysis teams, some ecological scientists elect to design survey instruments on their own, without the benefit of expertise in accepted social science theory and/or research methods (Pooley et al. 2014). Alternatively, decision analysis teams might choose to focus specifically on biological objectives and values, rather than including social values in the decision analysis, because they are either more comfortable with predicting ecological consequences (Johnson et al. 2015) or recognize that they do not have the expertise for the social component. To date, social scientists who have been asked to participate in a decision-analytic process have often played one of two roles. They have either been incorrectly perceived as "people managers," or "communicators," brought on as meeting facilitators to manage conflicts among stakeholders (Endter-Wada et al. 1998), or they have been sought as an afterthought to translate research results to the general public or stakeholders. Neither of these roles take full advantage of the contributions social science can make to decision analysis (Fox et al. 2006).

2) Decision analysis requires specialized skills

Decision analysis in natural resource applications has tended to focus on predicting ecological consequences of management actions and has generally stopped short of paying due diligence to the skill set that social scientists can bring to the analysis. Perhaps decision analysis teams assume that social scientists, by nature, are good communicators (see Challenge 1) and therefore can be called on to apply techniques that, in reality, require formal training in decision analysis. Decision analysis requires specialized skills, including predictive modeling, stakeholder feedback facilitation, and quantification of stakeholder values. Skills like eliciting values information from stakeholders in small group interviews or elucidating the range of value considerations across multiple groups (e.g., technical and lay audiences, interest groups; Gregory 2017), are unique to decision analysis and therefore common for neither ecologists *nor* social scientists.

3) (Mis)perceptions of social data

Decision analysts sometimes struggle to integrate social science into natural resource decision making because they are not aware that, or misunderstand how, core social science constructs (e.g., "social values") can be measured systematically and quantified (and hence, more easily integrated into decision making). This assumption that social values cannot be quantified has been invoked, for example, as a reason for difficulties in optimizing tropical finfish management decisions (Andalecio 2010). Moving towards systematic assessments of preferences can facilitate integration with ecological information in support of management thinking (see Stedman 2003). An unscientific approach to the social dimensions of a management problem (Challenge 1) can lead to poorly informed measures of stakeholder values: simply put, if decision analysis teams don't believe that social values can be measured, they are probably less likely to try to integrate them into decision-making processes.

4) Scale mismatches

Mismatches may exist between spatial and temporal scales required for decision analysis and social science. Many researchers have discussed potential resolutions for issues of scale in decision making for social-ecological contexts (see Holling 2001, Wilson et al. 2016). These authors described problems related to mismatches in human expectations for the timescale of ecological outcomes versus reality, as well as time required to observe the effect of technological and behavioral solutions. We suggest that timescale mismatches also occur because the time necessary to gather relevant social science, as well as biological, data can be at odds with the iterative nature of decision analysis. In decision analysis, the stakeholder group often iterates among the objectives-setting, alternative actions, and consequences steps of the process, as new information becomes available or discussions spur revisions (Hammond et al. 1999). For example, in the decision process for managing outbreaks of pneumonia in bighorn sheep (*Ovis canadensis*), four fundamental objectives were described in the first iteration of the decision analytic process (Mitchell et al. 2013). The working group refined the set of objectives to include a total of six fundamental objectives in the final version of the process (Sells et al. 2016), exemplifying the time that is often necessary to iterate through a decision analysis and finalize all components. While this iteration is a natural and useful part of the decision-making process, it can be problematic for predicting consequences of the actions on all objectives (ecological and social). In particular, social science tools like survey questions used to elicit stakeholder values and preferences require time for design, construction, dissemination, and analysis. When objectives change, revisions to the survey instrument might not be possible, or, at minimum, require additional time and money. Changes to surveys often require that the instrument be subjected to additional rounds of review by an institutional review board or subjected to other lengthy review processes from governments (e.g., the Paperwork Reduction Act in the USA) or universities, which can take time and require additional scrutiny. These temporal mismatches in the implementation of decision analysis can be frustrating for all parties involved, as groups struggle to reconcile the desire to define and analyze the problem as accurately as possible with the desire to make a decision as quickly as possible.

5) Human behaviors are difficult to predict

Even with the best models and data, human behavior is notoriously difficult to predict (Heberlein 2012), as multiple constraints prevent people from behaving in accordance with their beliefs and attitudes (Stern 2000). Accordingly, many of the most-used models (e.g., the Theory of Planned Behavior [Ajzen 1991]) have focused instead on understanding behavioral intention rather than actual behavior. This adds another crucial level of uncertainty to including human preferences in decision analysis—an uncertainty that is often misunderstood or overlooked by decision analysis teams. Values and basic beliefs do not directly predict specific behaviors (Vaske and Manfredo 2012), leading to uncertainty in the links among values, objectives, and predictive models of human behavior. Uncertainty in behavioral intention manifests as partial controllability—the difference between the intended and realized implementation of a management action, which can affect achievement of the objectives (Williams et al. 2002). Failure to account for partial controllability could lead to the choice of a suboptimal management action.

6) Failure of institutions to recognize the importance of social science

The integration of social and ecological science in decision analytic processes requires funding to support this work, including potentially increased funds for additional staff, survey instruments, and workshops. The typical funding sources for fish and wildlife management do not necessarily recognize the importance of this integration, and therefore might decline to fund more expensive projects that include social science. In addition, management and research institutions commonly fail to reward interdisciplinary work, and at times actively discourage ecologists from working on projects with substantial social components if such efforts are not seen as central to natural resource management. As long as funders and institutions fail to recognize the importance of social science in making management decisions, multi-objective decision making will likely not reach its full potential for aiding the resolution of difficult management problems.

Solutions and Suggestions for Integrating Social Science into Decision Analysis

Many of the challenges described above can be alleviated by adapting current practices or ways of thinking. We offer solutions for these challenges, as well as examples from the literature of how groups have overcome these challenges and integrated ecological and social sciences into their decision analyses.

1) Include social scientists at the beginning of the decision analysis

Decision analysis is a collaborative process that benefits from understanding and considering multiple perspectives about the problem being considered. Forming an effective team of collaborators with the necessary skills takes time, strategic thought, and effort. Thus, including social scientists fully at the beginning of a project is the first and most important step toward overcoming challenges to integration (Challenges 1–6, Figure 1; Endter-Wada et al. 1998). Establishing a multi-disciplinary team early in the process ensures that social scientists have the opportunity to participate in framing the problem and objectives and the time to collect needed data (Endter-Wada et al. 1998, Pooley et al. 2014). Often, a combination of small-group interactions among stakeholders and large-scale techniques, like surveys, is required to integrate social data fully into a decision analysis. The social data collected should directly relate to the objectives, which drive the rest of the decision analysis; inclusion at the outset provides opportunity for stakeholder input early in the decision process (Gregory and Keeney 1994). For example, biologists and anthropologists together led landowners through a series of workshops to make decisions for land use planning in western North Carolina, incorporating stakeholders' concerns at each step (Ferguson et al. 2015). This case demonstrates that when social scientists are included at the inception of a decision analysis, social values and ecological knowledge can each be considered thoroughly, potentially leading to fewer changes in the objectives as the process progresses, and partially alleviating timescale mismatches (Challenge 4).

Including social scientists at the beginning of a decision problem can be useful in an adaptive management context, as well. Uncertainty in natural resources management is not limited to ecological objectives, as human behavior is difficult to predict (Challenge 5), and uncertainties related to human values could affect the ultimate decision choice. As such, social scientists can first provide insight into the objectives setting process, ensuring that all sources of uncertainty are accounted for in the decision analytic framework. Second, social scientists can then provide the appropriate techniques for monitoring stakeholder values and behaviors in an adaptive management framework, providing data to update predictions of the achievement of social objectives like hunter satisfaction (Johnson et al. 2015) or behavioral changes associated with action implementation (Dhanjal-Adams et al. 2016).

2) Methods exist to quantify complex social values

Realizing that well-established, valid, and reliable protocols exist for measuring seemingly abstract social constructs, rather than assuming otherwise, can save decision analysts a great deal of time trying to create their own measures (Challenge 3). First, care must be taken to create a well-thought out set of objectives to ensure that the preferences expressed do not represent multiple meanings (Stedman 2003). We feel that it is all too common for an ecologist to attempt to characterize stakeholder satisfaction with a simple question, such as, "on a scale of 1–5 rate your satisfaction associated with white-tailed deer hunting." However, "hunter satisfaction" may be based on values of hunters who prefer to harvest different ages, sexes, and sizes of deer, each of which must be quantified separately, rather than including a general and overarching "hunter satisfaction" value, which would improperly lump diverse—or even competing—specific preferences (Robinson et al. 2016). Parsing social values as described above is an initial step in appropriately characterizing the social elements of a decision problem.

Constructed scales can provide a method to measure preferences or values that do not have a direct natural scale (Keeney 1992). A constructed scale is developed with the stakeholder group specifically for the stated objective. For example, members of the St'at'imc First Nations in British Columbia, Canada, created an objective for the "Cultural and Spiritual Quality of the River," including the smell, sound, sight, and feel of the river (Failing et al. 2013). By working with elders and community members, a quantitative, multidimensional scale was created to measure how specific water management techniques would affect this objective. Similarly, in considering non-native fish removal at the Glen Canyon Dam, USA, Native American tribes involved in the adaptive management process helped create scales for objectives of avoiding taking of life, respecting non-human life, respecting relationships between humans and non-humans, and protecting sacred sites (Runge et al. 2011a). Proxy attributes, indirect measures of an objective (Keeney 1992), can be used in the absence of a reasonable constructed scale. The Millennium Ecosystem Assessment used proxy attributes (or "indicators") to give a quantitative scale to some difficult-to-measure objectives (Alcamo et al. 2003). For example, they assessed human well-being by measuring rates of malnutrition. Through careful facilitation and elicitation of values, and by explicitly working with social scientists to measure them, these difficult-to-measure values can be integrated into the decision analysis.

3) Preferences and tradeoffs: combine the tools of decision analysis and social science

Making tradeoffs among competing objectives is one of the most important aspects of decision analysis (Hammond et al. 1999). The issues and objectives that are important to stakeholders in natural resource management problems require techniques that take into account the complexity, uncertainty, and potential controversy inherent in these decisions (Gregory et al. 1997). Decision-analytic tools like direct rating (Goodwin and Wright 2009) and swing weighting (Edwards and Barron 1994) are useful for eliciting objective tradeoffs in individual and small-group settings (Challenge 2). Analyses like downside weighting (Gregory et al. 2012) and value of information (Runge et al. 2011b) can demonstrate how uncertainties like partial controllability can affect the choice of management action (Challenge 5).

Engaging large groups of stakeholders to elicit preferences and tradeoffs requires a survey that can address the multiple value dimensions of stakeholders and identify their stance regarding key tradeoffs (Challenges 1, 2, 5; Gregory 2000). Attitude surveys that include not only a series of rating questions about preference (e.g., a Likert scale), but also a set of questions for ranking the objectives for the decision problem, can provide important information about how stakeholders value the complex set of objectives (Siemer et al. 2015, Robinson et al. 2016, 2017). This method still requires making inferences about how relative ranks translate into weighted objectives (see Robinson et al. 2016 for full description), but that process is much better informed if supported by good social data.

Stated-choice surveys are another good option for gathering necessary information from a large stakeholder group to make tradeoffs among objectives. These surveys ask respondents to choose from a hypothetical set of management actions that are described as ranges of objective measures (e.g., aspects of season choice for turkey hunting; Adamowicz et al. 1994, Schroeder et al. 2017). The range of predicted outcomes for each objective can be used to create a set of hypothetical actions. By asking respondents to state preferences for these hypothetical actions, social scientists can estimate the relative strength of options not actually presented to the respondents (i.e., the actual set of management actions under consideration; Louviere et al. 2000, Fieberg et al. 2010). In this way, stakeholders state their preference for a range of predicted outcomes for their objectives, rather than choosing an action directly, eliminating (potentially incorrect) inferences on the part of the stakeholder (Hunt et al. 2010). These preferences then can be incorporated directly into the analysis of tradeoffs (Schroeder et al. 2017). Although stated-choice surveys effectively gather social science data needed to make tradeoffs, they are complex to construct and analyze (Fieburg et al. 2010), underscoring the necessity of engaging social scientists at the beginning of the decision-analytic process (Challenge 1).

4) Methodological promise for future integration of ecological and social data

We believe that Social Values Mapping (Brown et al. 2004, Alessa et al. 2008) has great promise for decision analysis (Challenge 3). This approach explicitly maps environmental values (e.g., a metric of biological productivity) that are spatially coincident with human perceptions of the value of these locations. Mapping social values can be performed by participants manually with paper maps, or through more sophisticated computer-mapping systems. The resulting data can be analyzed using a variety of statistics, including the Getis-Ord GI* statistic (Getis and Ord 1992) that identifies clusters of points where social values are concentrated. Spatial representation of social values is particularly important for predicting consequences of management actions in a spatial context, given that social values often vary across geographic extent (Enck and Brown 2008, Leong et al. 2012). Indeed, local values are place-specific (Brown et al. 2002); identifying areas on the landscape that have high social values (e.g., biological, cultural, spiritual, aesthetic; see Alessa et al. 2008) allows for identifying “social-ecological hotspots” (areas where high social values and ecological values overlap). Additionally, researchers can identify “warmspots” (areas of low social values and high ecological values, or vice versa) and “coldspots” (areas of low social value and low ecological value), which may have even more relevance in certain decision contexts. For example, areas on the landscape represented as coldspots may be areas where management actions would be least detrimental, both socially and ecologically. Social values mapping would allow multiple ecological values to be included, provided there are spatial representations of the objective in question.

5) Publication and education

Full case studies of the use of decision analysis (either structured decision making or adaptive management) for natural resources management are still quite rare in the published literature (Runge et al. 2013, McGowan et al. 2015, Sells et al. 2016). As such, there are few examples of the use of this framework for management, and even fewer examples of the full integration of social science into decision analysis. In addition, finding appropriate outlets for publication of these case studies can be a challenge, as the paper can span ecology, social science, policy, and decision science, and may not fit in specialized journals. Publication of these case studies would be beneficial on multiple levels. By publishing these case studies more frequently, practitioners (both ecologists and social scientists) would be able to draw from the successes of and challenges faced by others in the field when implementing decision analysis projects (McGowan et al. 2015). Equally important, ecologists and managers would have a larger set of examples to draw from when crafting funding proposals that include social scientists and when funding, academic, or management institutions question the necessity of social science in management. Although the results of many decision analysis problems exist as reports on agency or university websites, the publication of these examples in the appropriate journals would extend the reach of these efforts to the broader community of practice.

In addition to publication, enhancing the community of practice for decision analysis in social-ecological systems requires enhanced education in ecological and social science programs.

For example, training ecologists about the importance of not only decision analysis, but the need to integrate social and ecological values into this framework, is necessary (Challenge 2). A basic understanding of social science techniques and theory, and how it can be integrated into decision making, would prepare this new generation of ecologists to seek out interdisciplinary avenues for decision analysis and eliminate the misunderstandings associated with the role of social science (Challenge 1) and how it can be used in a quantitative decision framework (Challenge 3).

Discussion

Decision analysis provides a framework to decompose a decision into a series of steps, including eliciting the values structure of stakeholders and using science, both ecological and social, to predict how management actions influence those values (Keeney 1992, 1996). Historically, however, applications of decision analysis to natural resource problems have focused heavily on ecological science, typically not applying social science in the process, and instead making assumptions or using unscientific information about social values.

In this paper, we have used "decision analysis" as a description for both structured decision making and adaptive management. We view adaptive management through the lens of the Decision-Theoretic school (McFadden et al. 2011), in which adaptive management is a special case of structured decision making for recurrent decisions with uncertainty. Therefore, social science can still be integrated into adaptive management, even when modeling strategies, such as dynamic programming, might preclude practitioners from incorporating multiple objectives in a utility function. Decision analysis, at its core, is a decision aiding technique (Gregory et al. 2001, Robinson and Fuller 2017), and as such, social science can be incorporated in the discussion of objectives, alternatives, and tradeoffs. In addition, social science can enable practitioners and decision makers to see when uncertainty in social objectives might affect the ultimate decision. Overall, we do not believe that integrating social science more fully into adaptive management frameworks is necessarily more difficult or impossible, but we do suggest that it will require careful planning and extra consideration.

Decision analysis offers an opportunity for expanding and improving integration of social science, but it will take effort and discipline to overcome persistent challenges. Among the challenges is the tendency of decision analysis teams (often led by ecologists) to attempt to fill all roles in a decision-analytic process, including social scientist, facilitator, communicator and, sometimes, proxy stakeholder representative and proxy decision maker. Other challenges are technical—the framework for decision analysis and the methods of social science do not always align in scale or timing, but these challenges can be addressed if they are recognized. In addition, technical challenges exist in social science, especially how to predict human behavior and how to quantify values in a way necessary for evaluating management actions. Finally, some challenges are institutional, such as the degree to which funders and other institutions (e.g., agencies and universities) emphasize the need for integration of social science into decision analysis.

Although this list of challenges is daunting, they can be overcome. We suggest that many operational challenges, in particular, can be remedied simply by including social scientists at the beginning of the decision-analysis process. Purposefully integrating ecological and social disciplines can also lead to overcoming other challenges. For example, by including social scientists in the process, the tools of both decision analysis and social science can be combined creatively to determine ways to quantify values, measure preferences, and make tradeoffs among management actions. In addition, practitioners can make use of other tools that are available to improve decision analysis, such as social values mapping. Finally, we suggest that publication of formal case studies of decision analysis for natural resources management, as well as more pointed integration of the benefits of interdisciplinary decision analysis in educational materials for the next generation of ecologists and social scientists, would provide tangible evidence of the benefits of including social science in decision analysis problems. Most importantly, integrating social science into decision analysis requires willingness of all parties to work together, in a collaborative, trusting fashion that is respectful and mutually reinforcing. We hope that by highlighting challenges and offering potential solutions, ecological and social scientists can work together more effectively to tackle complex natural resource management problems.

Literature Cited

Adamowicz W, Louviere J, Williams M (1994) Combining revealed and stated preference methods for valuing environmental amenities. J Environ Econ Manage 26:271–292

Ajzen, I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50:179–211

Alcamo J (2003) Ecosystems and human well-being: a framework for assessment. Island Press, London

Alessa L, Kliskey A, Brown G (2008) Social-ecological hotspots mapping: A spatial approach for identifying coupled social-ecological space. Landsc Urban Plan 85:27–39

Andalecio MN (2010) Multi-criteria decision models for management of tropical coastal fisheries. A review. Agron Sustain Dev 30:557–580

Bennett NJ, Roth R, Klain SC, Chan K, Christie P, Clark DA, Cullman G, Curran D, Durbin TJ, Epstein G, Greenberg A, Nelson MP, Sandlos J, Stedman R, Teel TL, Thomas R, Veríssimo D, Wyborn C (2017) Conservation social science: Understanding and integrating human dimensions to improve conservation. Biol Conserv 205:93–108

Brown GG, Reed P, Harris CC (2002) Testing a place-based theory for environmental evaluation: An Alaska case study. Appl Geogr 22:49–76

Brown G, Smith C, Alessa L, Kliskey A (2004) A comparison of perceptions of biological value with scientific assessment of biological importance. Appl Geogr 24:161–180

Decker DJ, Brown TL, Connelly NA, Enck JW, Pomerantz GA, Purdy KG, Siemer WF (1992) Toward a comprehensive paradigm of wildlife management: integrating the human and biological dimensions. In: Mangun WR (ed) American fish and wildlife policy: the human dimension. SIU Press, Carbondale, Illinois, USA, pp 33-54

Dhanjal-Adams KL, Mustin K, Possingham HP, Fuller RA (2016) Optimizing disturbance management for wildlife protection: the enforcement allocation problem. J Appl Ecol 53:1215–1224

Edwards W, Barron F (1994) SMARTS and SMARTER: improved simple methods for multiattribute utility measurement. Organ Behav Hum Decis Process 60:306–325

Enck JW, Brown TL (2008) 2007 Statewide deer hunter survey: participation during the ’06 seasons, opinions about hot-button issues, and trends in characteristics of hunters. Human Dimensions Research Unit Publication Series 08-5. Department of Natural Resources, Cornell University, Ithaca, New York

Endter-Wada J, Blahna D, Krannich R, Brunson M (1998) A framework for understanding social science contributions to ecosystem anagement. Ecol Appl 8:891–904

Failing L, Gregory R, Higgins P (2013) Science, uncertainty, and values in ecological restoration: A case study in structured decision-making and adaptive management. Restor Ecol 21:422–430

Ferguson PFB, Conroy MJ, Chamblee JF, Hepinstall-Cymerman J (2015) Using structured decision making with landowners to address private forest management and parcelization:

Balancing multiple objectives and incorporating uncertainty. Ecol Soc 20. https://doi.org/10.5751/ES-07996-200427

Fieberg J, Cornicelli L, Fulton DC, Grund MD (2010) Design and analysis of simple choice surveys for natural resource management. J Wildl Manage 74:871–879

Fox HE, Christian C, Nordby JC, Pergams OR, Peterson GD, Pyke CR (2006) Perceived barriers to integrating social science and conservation. Conserv Biol 20:1817–1820

Gannon JJ, Shaffer TL, Moore CT (2013) Native Prairie Adaptive Management: a multi region adaptive approach to invasive plant management on Fish and Wildlife Service owned native prairies. U.S. Geological Survey Open File Report 2013-1279, 184 p. with appendices.

Getis A, Ord JK (1992) The analysis of spatial association by use of distance statistics. Geogr Anal 24:189–206

Goodwin P, Wright G (2009) Decision analysis for management judgment. John Wiley & Sons, Ltd., West Sussex, United Kingdom

Gregory R (2000) Valuing environmental policy options: a case study comparison of multiattribute and contingent valuation survey methods. Land Econ 76:151–173

Gregory RS (2017) The troubling logic of inclusivity in environmental consultations. Sci Technol Human Values 42:144–165

Gregory RS, Failing L, Harstone M, Long G, McDaniels TL, Ohlson D (2012) Structured decision making: a practical guide to environmental management choices. Wiley-Blackwell, West Sussex, United Kingdom

Gregory R, Flynn J, Johnson SM, Satterfield TA, Slovic P, Wagner R (1997) Decision-pathway surveys: a tool for resource managers. Land Econ 73:240–254

Gregory R, Keeney RL (1994) Creating policy alternatives using stakeholder values. Manage Sci 40:1035–1048

Gregory RS, Keeney RL (2002) Making smarter environmental management decisions. J Am Water Resour Assoc 38:1601–1612

Gregory R, McDaniels T, Fields D (2001) Decision aiding, not dispute resolution: creating insights through structured environmental decisions. J Policy Anal Manag 20:415–432

Hammond JS, Keeney RL, Raiffa H (1999) Smart choices: a practical guide to making better life decisions. Broadway Books, New York, NY

Heberlein TA (2012) Navigating environmental attitudes. Conservat Biol 26:583–585

Holling CS (2001) Understanding the complexity of economic, ecological, and social systems. Ecosystems 4:390–405

Hunt LM, Gonder D, Haider W (2010) Hearing voices from the silent majority: a comparison of preferred fish stocking outcomes for Lake Huron by anglers from representative and convenience samples. Hum Dimens Wildl 15:27–44

Johnson FA, Boomer GS, Williams BK, Nichols JD, Case DJ (2015) Multilevel learning in the adaptive management of waterfowl harvests: 20 years and counting. Wildl Soc Bull 39:9–19

Keeney RL (1992) Value-focused thinking: a path to creative decision making. Harvard University Press, Cambridge, MA

Keeney RL (1996) Value-focused thinking: identifying decision opportunities and creating alternatives. Eur J Oper Res 92:537–549

Leong K, Decker DJ, Lauber TB (2012) Stakeholders as beneficiaries of wildlife management. In: Decker D, Riley SJ, Siemer WF (eds) Human Dimensions of Wildlife Management. The Johns Hopkins University Press, Baltimore, Maryland, pp 26–40

Louviere JJ, Hensher DA, Swait JD (2000) Stated choice methods: analysis and application. Cambridge University Press, Cambridge, MA

McDaniels T, Longstaff H, Dowlatabadi H (2006) A value-based framework for risk management decisions involving multiple scales: a salmon aquaculture example. Environ Sci Policy 9:423–438

McFadden JE, Hiller TL, Tyre AJ (2011) Evaluating the efficacy of adaptive management approaches: is there a formula for success? J Environ Manage 92:1354–9

McGowan CP, Smith DR, Nichols JD, Lyons JE, Sweka J, Kalasz K, Niles LJ, Wong R, Brust J, Davis M, Spear B (2015) Implementation of a framework for multi-species, multi-objective adaptive management in Delaware Bay. Biol Conserv 191:759–769

Mitchell MS, Gude JA., Anderson NJ, Ramsey JM, Thompson MJ, Sullivan MG, Edwards VL, Gower CN, Cochrane JF, Irwin ER, Walshe T (2013) Using structured decision making to manage disease risk for Montana wildlife. Wildl Soc Bull 37:107–114

Peterman R, Peters CN (1998) Decision analysis: taking uncertainties into account in forest resource management. In: Sit V, Taylor B (eds) Statistical methods for adaptive management studies. Land management handbook. BC Ministry of Forests, Victoria, BC, pp 105–128

Pooley SP, Mendelsohn JA, Milner-Gulland EJ (2014) Hunting down the chimera of multiple disciplinarity in conservation science. Conserv Biol 28:22–32

Raiffa H (1968) Decision analysis: introductory lectures on choices under uncertainty. Random House, New York, NY

Robinson KF, Fuller AK (2017) Participatory modeling and structured decision making. In: Gray S, Paolisso M, Jordan R, Gray S (eds) Environmental modeling with stakeholders: theory, methods, and applications. Springer International, Switzerland, pp 83–101

Robinson KF, Fuller AK, Hurst JE, Swift BL, Kirsch A, Farquhar J, Decker DJ, Siemer WF (2016) Structured decision making as a framework for large-scale wildlife harvest management decisions. Ecosphere 7:e01613. https://doi.org/10.1002/ecs2.1613

Robinson KF, Fuller AK, Schiavone MV, Swift BL, Diefenbach DR, Siemer WF, Decker DJ (2017) Addressing wild turkey population declines using structured decision making. J Wildl Manage 81:393–405

Runge MC, Bean E, Smith DR, Kokos S (2011a) Non-native fish control below Glen Canyon Dam — report from a structured decision-making project. Reston, VA

Runge MC, Converse SJ, Lyons JE (2011b) Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. Biol Conserv 144:1214–1223

Runge M, Grand J, Mitchell MS (2013) Structured Decision Making. In: Krausman P, Cain III J (eds) Wildlife Management and Conservation: Contemporary Principles and Practices. The Johns Hopkins University Press, Baltimore, Maryland, pp 51–72

Schroeder SA, Fulton DC, Cornicelli L, Merchant SS (2017) Discrete choice modeling of season choice for Minnesota turkey hunters. J Wildl Manage online early. https://doi.org/10.1002/jwmg.21382

Sells SN, Mitchell MS, Edwards VL, Gude JA, Anderson NJ (2016) Structured decision making for managing pneumonia epizootics in bighorn sheep. J Wildl Manage 80:957–969

Siemer WF, Decker DJ, Stedman RC (2015) Hunter satisfactions with deer harvest opportunities in New York State. Human Dimensions Research Unit Publication Series 15–05. Department of Natural Resources, Cornell University, Ithaca, New York

Stedman RC (2003) Sense of place and forest science: toward a program of quantitative research. For Sci 49:822–829

Stern PC (2000) New environmental theories: toward a coherent theory of environmentally significant behavior. J Soc Issues 56:407–424

Vaske JJ, Manfredo MJ (2012) Social psychological considerations in wildlife management. In: Decker D, Riley SJ, Siemer WF (eds) Human Dimensions of Wildlife Management. The Johns Hopkins University Press, Baltimore, Maryland, pp 43–57

Williams BK, Johnson FA (1995) Adaptive management and the regulation of waterfowl harvests. Wildl Soc Bull 23:430–436

Williams BK, Nichols JD, Conroy MJ (2002) Analysis and management of animal populations: modeling, estimation, and decision making. Academic Press, San Diego, California

Wilson RS, Hardisty DJ, Epanchin-Niell RS, Runge MC, Cottingham KL, Urban DL, Maguire LA, Hastings A, Mumby PJ, Peters DPC (2016) A typology of time-scale mismatches and behavioral interventions to diagnose and solve conservation problems. Conserv Biol 30:42–49

Fig. 1 Integration of social science into decision analysis occurs at all steps in the process (adapted from Runge et al. 2013)