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Using expert judgments to inform economic evaluation of ecosystem-based adaptation decisions: watershed management for enhancing water supply for Tegucigalpa, Honduras

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Abstract Acute concerns over the status of ecosystems providing benefits to human communities, and deep uncertainties over the consequences of future climate change, call for new policy choices, as well as improved methods for analysis. This paper considers the profoundly important and under-recognized role of structured judgments provided by technical specialists with local experience in relevant ecological and technological systems, in order to inform climate change adaptation choices, including ecosystem-based adaptation (EBA). It begins with a brief review of the concepts and methods for eliciting judgments from technical experts for complex decisions under uncertainty. Then, the case study is described: an expert judgment task to assess the performance of the recently approved watershed management plan for the Guacerique watershed near Tegucigalpa, Honduras. Several key variables including water yield in dry seasons, cost changes and also more broadly defined ecosystem service benefits, under two climate scenarios, are employed to consider performance. The results provide resource managers with information on how to maximize the adaptation potential of an already approved management plan. It shows that estimates of potential enhanced water flows in dry seasons could yield millions of dollars in annual benefits, based on current water prices paid to informal water suppliers, and depending on future climate scenarios. A broader implication of the study is to document a relatively accessible, cost-effective approach to support policy decisions related to EBA and infrastructure, which is relevant for decisions to help achieve the United Nation's Sustainable Development Goals.

Keywords Structured judgments · Expert judgments · Ecosystem-based adaptation · Decision-making under uncertainty

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1 Introduction

Societies around the globe face environmental degradation, a changing climate and a need for adaptation given declining provision of ecosystem services (Millennium Ecosystem Assessment 2005; Intergovernmental Panel on Climate Change (IPCC) 2007; Moser and Ekstrom 2010). These challenges are particularly acute in the developing world. Several authors and organizations have called for enhanced efforts to promote ecosystem-based adaptation to climate change. Ecosystem-based adaptation (EBA) *is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse impacts of climate change* (SCBD 2009). Researchers argue that EBA options offer lower cost, lower risk, more accessible and easily implemented adaptation opportunities than those based largely on infrastructures (Andrade et al. 2011; McKinnon and Hickey 2009; Munang et al. 2013; UNFCCC 2013; Vignola et al. 2009). Innovative analytical approaches are required to support these complex decisions (Lempert 2002; Morgan et al. 1999; Cooke and Goossens 2004; McDaniels et al. 2012).

One innovative approach with scope to provide insights into ecosystem adaptation alternatives is greater reliance on structured judgments of experts. Over the last three decades, analysts have placed greater emphasis on probabilistic expert judgment in many contexts, ranging from potential effects of new technologies, and hazardous industrial activities to natural resource management, conservation issues and climate change, for both processes and impacts (Cooke and Goossens 2004; Flari et al. 2011; Keeney and von Winterfeldt 1991; McDaniels 1995; McDaniels et al. 2012; Morgan et al. 2006; Morgan and Keith 1995; Morgan et al. 2001; Otway and von Winterfeldt 1992; Teck et al. 2010; Zickfield et al. 2007). A recent paper by Morgan (2014) provides an overall characterization of the use of expert judgments in characterizing uncertainties regarding hazards, ecological change and other contexts. Oppenheimer et al. (2016) and Mach et al. (2017) both discuss the use of expert judgments in the context of climate change assessments.

While expert judgments are increasingly recognized as crucial input for complex choices, there is an important role for further studies that demonstrate the use of such judgments in novel contexts, and with novel judgment scales that address variables or dimensions not formerly seen in other studies, as is the case with ecological productivity from ecosystem-based adaptation. There is also value in preliminary analysis that illustrates which variables and inputs have the greatest impact on the value of alternatives, as guidance for further studies or transferring results to related contexts. Finally, the benefits of reliance on the informed views of local experts in the systems of interest are clear when the huge gaps in data for modelling approaches are recognized, particularly in the developing world.

The broad objective of this paper is to demonstrate that technical judgments (about the performance of alternatives), and value judgments (about how to evaluate EBA compared with infrastructure-based adaptation alternatives of different scales), will invariably be required to understand the consequences of EBA under climate change. A second, more specific objective is to present and demonstrate an approach for eliciting expert judgments from locally informed technical specialists to characterize how a given EBA alternative is likely to perform in terms of fundamental objectives important for society. While modelling approaches are often seen by many as the ideal way to characterize the ecological productivity of adaptation or management alternatives, the lack of localized data to estimate such ecological production functions is a severe obstacle (Daily et al. 2009). More broadly, the lack of experience with localized ecological productivity in a changing climate, and the lack of resources or data for such efforts in most places around the world, make reliance on structured expert judgments a reasonable and practical step to characterize the performance of alternatives (McDaniels et al. 2012). A third specific objective is on the valuation side. Here, we argue that the costs of infrastructure-based alternatives (broadly defined to include any investment in physical systems to enhance ecosystem services) can be used as a basis for estimating the costs avoided through an EBA alternative, after adjusting for different scales of cost and production. Hence, along with previous studies (Jones et al. 2012), we argue that the avoided cost of new infrastructure can serve as basis for estimating EBA benefits. A fourth objective is to demonstrate how structured judgments within a systems-based context, provided by technical specialists with local experience in relevant ecological and technological systems, can help inform adaptation choices. To achieve this objective, we develop and employ judgments scales to structure flexible judgment tasks that can be applied and adapted at local scales with limited financial, analytical and information capabilities.

The setting for this research is the Guacerique River watershed near Tegucigalpa, Honduras. A major watershed management plan has recently been approved for this watershed, in hopes of protecting and enhancing municipal water supply for Tegucigalpa, which is partially drawn from the Guacerique River. This city is chronically short of water supply, particularly in the dry season, and plans have been made to develop major new sources of supply from other nearby watersheds, involving very large infrastructure costs (Vignola et al. 2015).

This research involved designing and applying a set of expert judgment elicitation tasks to obtain probabilistic estimates from technical specialists in watershed management and drinking water infrastructure with knowledge of the Guacerique River watershed. The elicited judgments were used to estimate the economic benefits of forest-based watershed management interventions in terms of effects on water provision (quantity and quality) for the city of Tegucigalpa, given scenarios of climate change over a 20-year time horizon. As will be seen, the most notable benefit of the watershed management activities is estimated to be improved yield of water during the dry season, when water supply is extremely scarce.

This paper is organized into five sections. Section two introduces relevant concepts and methods, for expert judgment tasks, and describes two specific examples relevant to this study. Sections three presents the methods, and Section four the results of the expert elicitation tasks conducted for this study. Section five provides discussion and conclusions.

2 Concepts and methods for using expert judgments in adaptation decisions

Judgments to characterize uncertain consequences are an inherent part of all complex decisions, although they are not always explicit (Cooke and Goossens 2004; Keeney and von Winterfeldt 1989, 1991; Otway and von Winterfeldt 1992). Probability elicitation stems from a Bayesian view of probability, with the emphasis not on updating after new information, but on capturing current beliefs of experts, given all information currently at hand (Morgan 2014). Formal judgment elicitations are structured exercises used to capture experts' explicit views on uncertain variables to make these views more explicit and relevant for analysis (Flari et al. 2011; Keeney and von Winterfeldt 1991; Morgan 2014; Oppenheimer et al. 2016). Expert judgments can be used to explore the potential relative contributions of different variables to the dynamics of highly complex systems (McDaniels et al. 2012; Morgan and Keith 1995; Morgan et al. 2001; Teck et al. 2010; Zickfield et al. 2007). Given the non-stationary climate future faced by the world, judgments can be used to characterize how ecological or technical systems may perform under new climate stresses, even though direct experience with changing conditions is lacking in a given location. These judgments can be made conditional on a range of climate scenarios (McDaniels et al. 2012). Thus, expert judgments can be directly relevant for ecosystem-based climate change adaptation decisions.

Experts may be asked to assess the likelihood of an event (subjective probability) or provide comparative assessments (relative likelihoods or rankings) (Cooke and Goossens 2004; Keeney and von Winterfeldt 1989, 1991). Subjective probability elicitation is the more common approach. Respondents are asked to think about a specific phenomenon, conditional on various assumptions about states of the world, and express the full range of potential occurrence (bounding) and the corresponding fractiles to create a probability distribution (Clemen and Winkler 1999; Cooke and Goossens 2004; Keeney and von Winterfeldt 1989, 1991). Probabilities are often displayed as cumulative density functions (e.g. Keeney and von Winterfeldt 1991) or box plots (e.g. Morgan et al. 2006; Morgan and Keith 1995; Zickfield et al. 2007).

A variant is to elicit expert opinion directly on conditions that may influence performance of alternatives, such as the extent to which a specific policy decision can be expected to meet its intended objectives under a specific set of conditions (McDaniels et al. 2012). In all cases, results of judgment exercises can highlight the diversity of opinion (and uncertainty) surrounding issues of concern, and point to choices that are more robust over a range of future conditions (Keeney and von Winterfeldt 1991; Morgan and Keith 1995; Morgan et al. 2001).

A formal judgment exercise commonly consists of a sequential set of basic steps: (1) issue identification and selection, (2) expert identification and selection, (3) issue discussion and refinement, (4) training for elicitation, (5) elicitation, (6) analysis and (7) documentation and communication (Cooke and Goossens 2004; Keeney and von Winterfeldt 1991; Otway and von Winterfeldt 1992; Morgan 2014). Expert judgment exercises can involve an array of experts, depending on the issue at hand. Some have argued for the calibration of expert opinion, through questions that attempt to establish the quality and reliability of judgments from individual experts (Cooke and Goossens 2004; Oppenheimer et al. 2016). Such an approach requires a wide array of experts to be available and qualified for a given task, which often does not hold for situations in which local ecological knowledge is important (McDaniels et al. 2012).

The elicitation exercise (step 5) consists of the presentation of conditioning information thought to influence the variables under consideration and, subsequently, the recording of responses to specific questions. Several elements have shown to improve forecasts including: clearly structured contexts and scenarios, graphical communication of relevant information including influence diagrams, alerting participants to potential cognitive bias and the use of workable judgment tasks and scales (McDaniels et al. 2012). When employed, constructed scales, including Likert scales, need to be meaningful, clear and practical (McDaniels et al. 2012; Streiner and Norman 2008).

Probabilistic judgments are most often elicited individually. Responses can then be reported individually, and if relevant, combined, by averaging or with scoring rules. An alternative, but criticized approach, is to use deliberative discussion to arrive at consensus based probability judgments (Clemen and Winkler 1999; Cooke 1991; Morgan and Keith 1995; Zickfield et al. 2007).

Some the principle challenges are the influence of problem structuring on outcomes (Otway and von Winterfeldt 1992), and mitigating the influence of cognitive bias, especially overconfidence, anchoring and availability, on logical reasoning (Cooke 1991; Cooke and Goossens 2004; Keeney and von Winterfeldt 1991). The methodological design of the research presented in this article builds on the lessons learnt by previous analysis to address these biases (see for example Keeney and von Winterfeldt 1991; McDaniels 1995; McDaniels et al. 2012; Morgan et al. 2006; Morgan and Keith 1995; Morgan et al. 2001; Zickfield et al. (2007)). Key approaches are described below.

3 Methods

3.1 The case study context

This study sought to analyse the benefits of an ecosystem-based adaptation (EBA) alternative (namely a watershed management plan) compared to investment in infrastructure. The objectives of the watershed management alternative include improvements to municipal water supply in Tegucigalpa, Honduras (measured in terms of cost savings to the national water utility), and improved ecosystem service provision within the watershed. The study focused on the Guacerique watershed in the Francisco Morazán province, northwest of Tegucigalpa, Honduras, which has a land area of 191.75 km^2. The government of Honduras has identified the watershed as one of the areas of the country most vulnerable to climate change (SERNA 2000).

The Guacerique watershed is of specific importance to national authorities as it currently supplies water to approximately 25% of connections in Tegucigalpa. Combined processes of deforestation, land conversion to agriculture and human settlement and climate change are adversely affecting water supply. Sediment accumulation is estimated to have reduced reservoir capacity by 15%, and treatment costs have risen dramatically over the last 15 years (per. comm.), when the water supply system was severely impacted by Hurricane Mitch in 1998 (Vignola et al. 2015).

In response, the national water utility and the Honduran Ministry of Forests have developed a 6-year watershed management plan. The plan received official approval in late 2012, allowing authorities to proceed with implementation. The watershed management plan seeks to ensure long-term water availability and lower sediment loads on the Guacerique River in order to maximize the watershed's utility as a source of drinking water for Tegucigalpa.

The study occurs in the context of overarching global concerns of the impact of climate change on human well-being and considerable local challenges, both current and foreseen, to providing sufficient clean drinking water to both urban and rural dwellers in Honduras. Local challenges include deficient infrastructure, inability to meet current water demand in the city of Tegucigalpa and dependence on surface water as sources of drinking water. Changing precipitation patterns and increased variability in river flow levels could decrease water availability for human consumption and further diminish water quality, while population and economic growth continue to increase demand. The watershed management plan represents a 'policy-first' approach (Ranger and Garbett-Shiels 2012) as it contributes to existing national and local priorities in addition to addressing the potential impacts of climate change.

3.2 Methods employed

The research project estimated the impact of the proposed Guacerique watershed management plan on water supply and other ecosystem service provision in the watershed and calculated the value of the estimated improvements to water quality and quantity to the national water utility (and the nation) under two climate change scenarios. Expert judgment was used to estimate the impact of specific management options on defined ecosystem services under the two climate change scenarios. Economic valuation was then applied to experts' projections of benefits accruing to the national water utility (specifically increased drinking water availability, maintenance of storage space, and reductions in treatment costs) using a combination of willingness-to-pay and replacement cost approaches to ecosystem service valuation.

The authors adopted the standard expert elicitation framework to carry out the study combined with the application of an ecosystem services perspective. One important variation is how training for elicitation was addressed (see Sect. 3.2.4). The specific methods employed for each of the 7 steps are described below.

3.2.1 Issue identification and selection

The study was undertaken as part of a multi-country research initiative, which sought to assess the role of forests in boosting social and environmental resilience through ecosystem-based adaptation to climate change using a 20–50-year time horizon. The research in the case study was carried out in conjunction with two principal local partners: Honduras' national water utility (SANAA) and Ministry of Forests (ICF). These local actors have developed and approved the Guacerique watershed management plan to improve drinking water availability and quality for Tegucigalpa residents. Initial interviews with SANAA managers within the context of eliciting interest in participating in the initiative, the proposed plan, as well as existing literature on the watershed and its drinking water infrastructure, provided the basis for initial issue identification. Mapping the system (Fig. 1) also contributed to identifying issues and initial selection of relevant variables and was presented to experts as part of the background information during the elicitation.

3.2.2 Expert identification and selection

Experts were sought through staff members and advisors from within the national water utility. Snowball sampling was used to expand the pool of experts beyond the group identified during the initial phases of the research project. Experts were identified as individuals directly involved in the watershed planning process, in the management of water supply infrastructure in the watershed or in developing related infrastructure investment plans. From a systems' perspective, this approach brought together experts

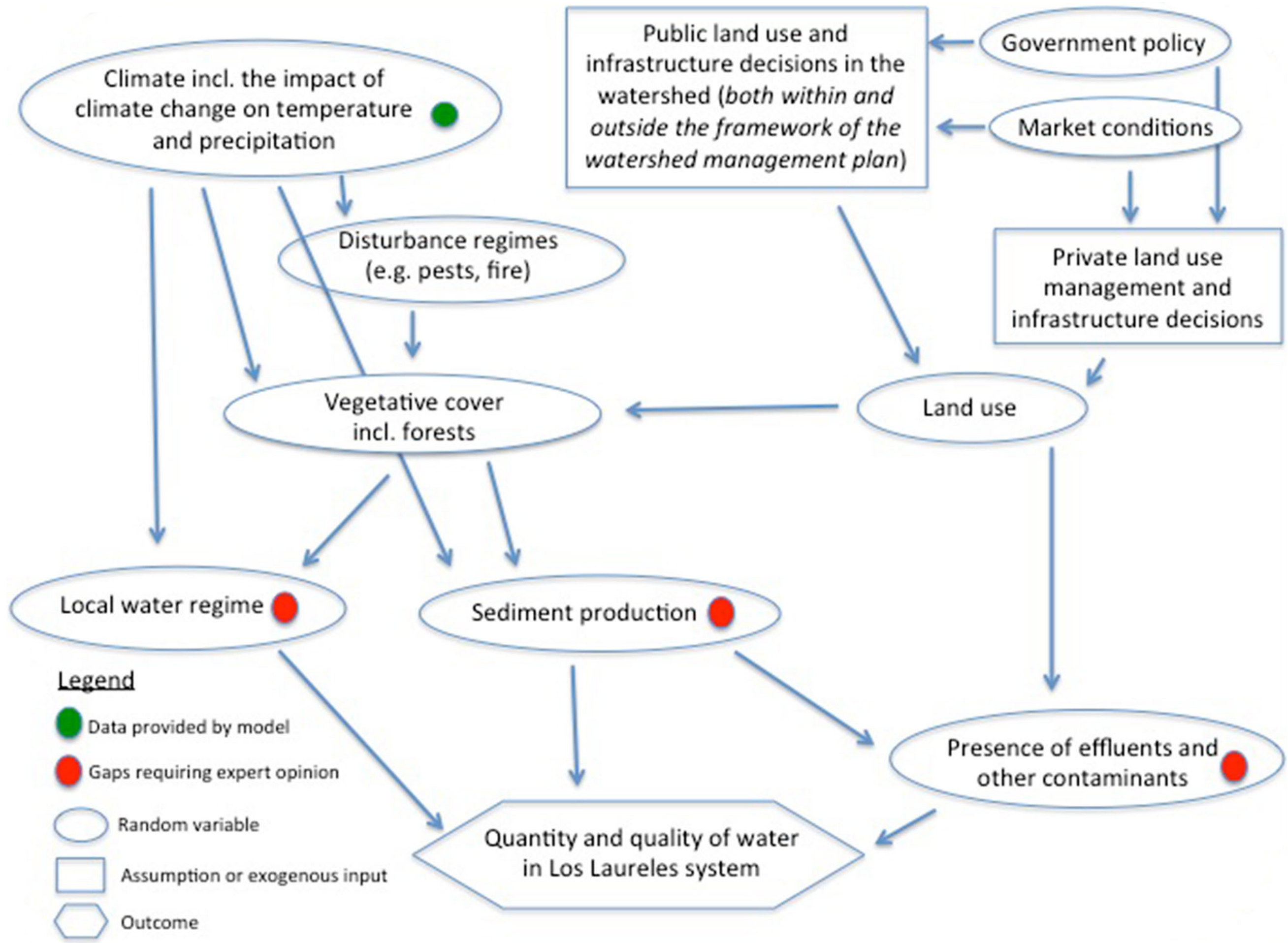

Fig. 1 Influence diagram showing the relationships for factors that affect water quality and quantity in the Guacerique River watershed

in upstream (watershed) dynamics and characteristics and downstream (infrastructure) management and decision-making. A total of 10 experts were identified and participated in the elicitation process; experts were individuals from the institution's watershed management unit (6), infrastructure units (3) and the head office (1). Experts were chosen rather than civil society representatives or citizen decision makers, because we were seeking to characterize the technical performance of the alternatives for the purpose of an economic valuation exercise. Experts are the natural source of such information, whereas citizen decision makers would be relevant if we were seeking to elicit their values regarding the alternatives (i.e. stakeholder expressed preferences).

3.2.3 Issue discussion and refinement

Prior to the elicitation process, researchers carried out preliminary in-person interviews with SANAA and ICF representatives in Tegucigalpa to establish system characteristics, key variables and links, and test questions and response scales. These interviews elucidated experts' main areas of concern and relevant indicators for evaluating drinking water objectives: (1) amount of drinking water available for SANAA clients (Tegucigalpa residents and businesses) and (2) the quality of the water entering the treatment plant. Furthermore, experts identified turbidity and dissolved oxygen levels as key quality indicators for the wet and dry season, respectively. Thus, part of the judgment task focused on the impact of the watershed management plan on four variables: (1) reservoir sedimentation rates, (2) turbidity levels in the reservoir, (3) dissolved oxygen levels in the reservoir during the annual dry season (December–May) and (4) the amount of water entering the reservoir during the annual dry season.

The other area of exploration was the importance, extent (physical distribution) and substitutability of ten different ecosystem services (fresh water, fibre, fuel, erosion regulation, pest regulation, pollination, natural hazard regulation, soil formation, nutrient cycling and recreation/ecotourism) as well as estimate distribution of benefits among five beneficiary groups (down-, mid- and upstream

Table 1 Scenarios used for the judgment task on general ecosystem service provision

Scenario A	It is the year 2030. In this scenario, the watershed management has NOT been implemented. Land use change and demographic growth for the period 2010–2030 have been similar to observed changes in the period 1990–2010. The LOW climate change assumptions have proven correct
Scenario B	It is the year 2030. In this scenario, the watershed management has been fully implemented as described in Section G1, curbing land use change and deforestation. Demographic growth for the period 2010–2030 has been similar to observed changes in the period 1990–2010. The LOW climate change assumptions have proven correct
Scenario C	It is the year 2030. In this scenario, the watershed management has NOT been implemented. Land use change and demographic growth for the period 2010–2030 have been similar to observed changes in the period 1990–2010. The HIGH climate change assumptions have proven correct
Scenario D	It is the year 2030. In this scenario, the watershed management has been fully implemented as described in Section G1, curbing land use change and deforestation. Demographic growth for the period 2010–2030 has been similar to observed changes in the period 1990–2010. The HIGH climate change assumptions have proven correct

Table 2 High and low climate change scenarios for the 2030 time horizon for the Guacerique watershed

Climate variable	Value	Impact
Low climate change scenario (in 2030) for the Guacerique watershed		
Change in mean annual temperature	+0.65 °C	Mean annual temperature reaches 23 °C
Change in mean annual precipitation	−21.7%	Mean annual precipitation decreases to 894 mm.
High climate change scenario (in 2030) for the Guacerique watershed		
Change in mean annual temperature	+1.51 °C	Mean annual temperature reaches 23.9 °C
Change in mean annual precipitation	+5.37%	Mean annual precipitation increases to 1200 mm

watershed inhabitants, national water utility and other downstream users). The Millennium Ecosystem Assessment (2005) provided the basis for the classification of ecosystem services. Experts evaluated provision under four scenarios combining successful completion of the watershed management plan versus a business as usual scenario with the high and low climate scenarios. The four land use-oriented scenarios are described in Table 1 and the climate scenarios in Table 2. Further details are provided in Vignola et al. (2015).

3.2.4 Elicitation

The elicitation occurred in a 1-day workshop setting held in Tegucigalpa in October 2012. The elicitation was split into two separate tasks: six of the 10 experts considered the performance of variables related to the drinking water infrastructure under the specific management options and climate change scenarios and four considered the impact of specific management options on general ecosystem service provision within the watershed under the two climate change scenarios.

Experts were provided with a workbook containing background material (summarizing key observations regarding geography, economy and demography of the watershed), the two climate change scenarios and the management scenario as well as a question section to record responses (Vignola et al. 2015 provides all text and details). The first portion of the workshop consisted of a review and open discussion of the background material provided in the workbook. This exercise aimed to make the relevant information equally available to the experts and to ensure common understanding of the scenarios under consideration. Then, experts were asked to read the questions and respond individually, recording answers in their own workbook, without consulting peers. Experts were encouraged to ask aloud any questions that arose or clarifications they required to allow for answers to be provided to the whole group. In addition, on specific questions, experts were asked to record their rationale to facilitate consistency checks during the data analysis phase.

The confidence of the participants was addressed in this judgment task through the use of the three-point probability elicitation routine used by McDaniels et al. (2012), and then an additional question asked participants about their confidence in their judgments. On a second scale, from 0 to 10 (no confidence to absolute confidence), experts rated their confidence level in their response.[1]

[1] Based on recent research, an alternative and more quantitatively direct approach would have been to adopt the approach of Speirs-Bridge et al. (2010), which asks four point judgments in which the final question seeks the expert's view on the range of uncertainty addressed between their highest and lowest expressed points. That approach has been demonstrated in experimental studies to reduce overconfidence.

3.2.4.1 Judgment task in more detail: scenarios under consideration Two climate change scenarios were constructed to represent the "high" and "low" extremes along the continuum of possible future climates for the watershed. Temperature and precipitation data for all SRES AR4 scenarios for the 2030 time horizon (2010–2039) for the geographic coordinates closest to the coordinates of the case study were ordered in ascending values. The tenth percentile value was considered the low climate change scenario (i.e. one in ten chance that the mean would be lower than this value), and the ninetieth percentile value was considered the high climate change scenario (i.e. one in ten chance that the mean would be higher than this value). Table 2 shows the scenarios as presented to the experts in the judgment elicitation workbook.

The management scenario was summarized as the full implementation of the tree- and soil-specific aspects of the watershed management plan over the course of the planned 6 years (2013–2018) and the maintenance of these achievements over the subsequent 11 years (2019–2029). Thus, in the year 2030, it could be assumed that all reforestation activities have led to the establishment of young forest stands and the benefits resulting from these activities continue to manifest in and beyond the watershed. Table 3 contains the management scenario presented to experts.

3.2.4.2 Judgment task in more detail: questions and evaluation scales In both cases, experts were asked to estimate the performance of these variables in the year 2030 assuming the successful implementation of the watershed management plan under first the "low" and second the "high" climate change scenario. Responses were recorded using Likert scales. The specific questions asked of the experts for each of the variables related to drinking water infrastructure are presented in Table 4 and for general ecosystem service provision are presented in Table 5. Figure 2a, b shows the response scales used to record judgments on these questions.

Scales were developed that were clear and functional for experts. Scales were tested with selected experts during a preliminary trial of the judgment task and subsequently adjusted (range and intervals). For the judgment task in relation to future performance of specific variables related to drinking water infrastructure, judgments were provided in terms of percent change in relation to average variable performance over the last 20 years. These scales were generally composed of integers, generally from −5 to +5 with zero in the middle where zero represented no change, and 5 a 50% deviation from the average in either direction. See Fig. 2a. Experts generally perceived 50% as sufficient range, although in one case (water provision), after expert consultation, the scale was extended to 10 or 100% change.

Table 3 Management scenario considered by experts during the expert judgment elicitation

Given that our purpose is to study the impacts of forest management on ecosystem service provision, we are particularly interested in the forest- and soil-related activities. Thus, for the purposes of this study we have summarized the watershed management plan as follows
1. Reforest 1236 ha around springs and creeks
2. Create 100 ha of fuel wood plantations
3. Transition to agroforestry on 161 ha of steeply sloping agricultural land (30% slopes)
4. Concentrate forest fire control on reforested areas
5. Reduce illegal timber extraction on 6063 ha classified as forest reserve
6. Concentrate pest control on 4338 ha of existing pine forests; and
7. Implement soil conservation measures on 2000 ha of agricultural fields

Table 4 Questions regarding the future performance of specific variables related to drinking water infrastructure used to elicit expert judgments

H2.1	Under the low climate change scenario, what effect will the watershed management plan have on sediment accumulation in the reservoir?	H3.1	Under the high climate change scenario, what effect will the watershed management plan have on sediment accumulation in the reservoir?
H2.3	Under the low climate change scenario, what effect will the watershed management plan have on turbidity levels in the reservoir?	H3.3	Under the high climate change scenario, what effect will the watershed management plan have on turbidity levels in the reservoir?
H2.6	Under the low climate change scenario, what effect will the watershed management plan have on dissolved oxygen levels in the reservoir *during the annual drying period*?	H3.6	Under the high climate change scenario, what effect will the watershed management plan have on dissolved oxygen levels in the reservoir *during the annual drying period*?
H2.9	Under the low climate change scenario, what effect will the watershed management plan have on water inflow into the reservoir *during the annual drying period*?	H3.9	Under the high climate change scenario, what effect will the watershed management plan have on water inflow into the reservoir *during the annual drying period*?

Table 5 Questions regarding the future ecosystem service provision used to elicit expert judgments

H5.5	Please rate, on a scale of 1–7, the extent of each of the following ecosystem services in the Guacerique watershed in 2030? Extent refers to the area of the watershed that provides the ecosystem service
H5.6	Please rate, on a scale of 1–7, the importance of the following ecosystem services in the Guacerique watershed in 2030. Importance refers to the contribution of the ecosystem service to wellbeing in the watershed
Note: Questions H5.5 and H5.6 were repeated under the four different scenarios as described below	
A	It is the year 2030. In this scenario, the watershed management has NOT been implemented. Land use change and demographic growth for the period 2010–2030 have been similar to observed changes in the period 1990–2010. The LOW climate change assumptions have proven correct
B	It is the year 2030. In this scenario, the watershed management has been fully implemented as described in Section G1, curbing land use change and deforestation. Demographic growth for the period 2010–2030 has been similar to observed changes in the period 1990–2010. The LOW climate change assumptions have proven correct
C	It is the year 2030. In this scenario, the watershed management has NOT been implemented. Land use change and demographic growth for the period 2010–2030 have been similar to observed changes in the period 1990–2010. The HIGH climate change assumptions have proven correct
D	It is the year 2030. In this scenario, the watershed management has been fully implemented as described in Section G1, curbing land use change and deforestation. Demographic growth for the period 2010–2030 has been similar to observed changes in the period 1990–2010. The HIGH climate change assumptions have proven correct

Seven-point scales as well as open-ended questions were used for the ES provision judgment task. Seven-point scales are considered optimal for Likert scales (Streiner and Norman 2008). In this case, one represented no present/not important and seven represented everywhere/very important with other numbers representing mid-points between these two extremes.[2] See Fig. 2b.

3.2.5 Response analysis

Recall that issues of the calibration or the quality of judgments expressed among experts have been discussed in the recent writing (Oppenheimer et al. 2016). Because of the complex nature of the judgment tasks, we addressed calibration or judgment quality in an innovative way in this study. Written explanations of responses provided by experts in the workbook were used to compare logic with responses and ensure consistency in responses. The review process led to some responses being removed from the data set. For example, for one question, one expert based his reasoning on an increase in precipitation, yet the scenario being considered in the question showed a significant decrease in precipitation, so that response we deleted from the data. No expert had all their estimates removed, indicating they generally understood the judgment tasks.

3.2.6 Economic valuation

The economic valuation was developed based on the estimates derived from the drinking water outcome judgment task, specifically the changes in performance of variables related to drinking water infrastructure under the two climate change scenarios. Economic benefit was estimated using net present value analysis.

The responses of the various experts regarding the impact of the watershed management activities on water-related variables were averaged. This is a common approach to combining the views of experts when distributions are generally unimodal, and when there is no additional information regarding calibration of experts (McDaniels et al. 2012). An analysis that employed the confidence judgments of each expert as a basis for calibration and weighting the estimates was considered. Given the widespread tendency towards overconfidence in expert judgments, this approach was rejected. A different approach would be to conduct the analysis for each expert separately. Then, the impact on the analysis of different views could be compared. That approach was rejected because we would have no way to interpret any potential differences; moreover, the experts expressed a desire to have the results considered together.

3.2.6.1 Annual benefit calculation The value of improvements in water provision (quality and quantity) was calculated in three different ways, for three different water provision variables. First, the *unit cost of specific treatment chemicals whose use would be avoided due to improved quality of incoming water* was used to value changes in water quality achieved through the watershed management plan. Second, *the value of incremental reservoir water storage capacity created* was calculated on the basis of the unit cost of the proposed Guacerique II reservoir project, with these costs drawn from the relevant engineering studies (Vignola et al. 2015). Reservoir construction costs were transformed into 2012 dollars using an appropriate construction price index for the region.

[2] The end- and mid-points were defined as: 1 = watershed does not provide ES, 4 = half of the watershed area provides the ES, and 7 = the entire watershed provides the ES. These statements were presented above the response table in the response workbook.

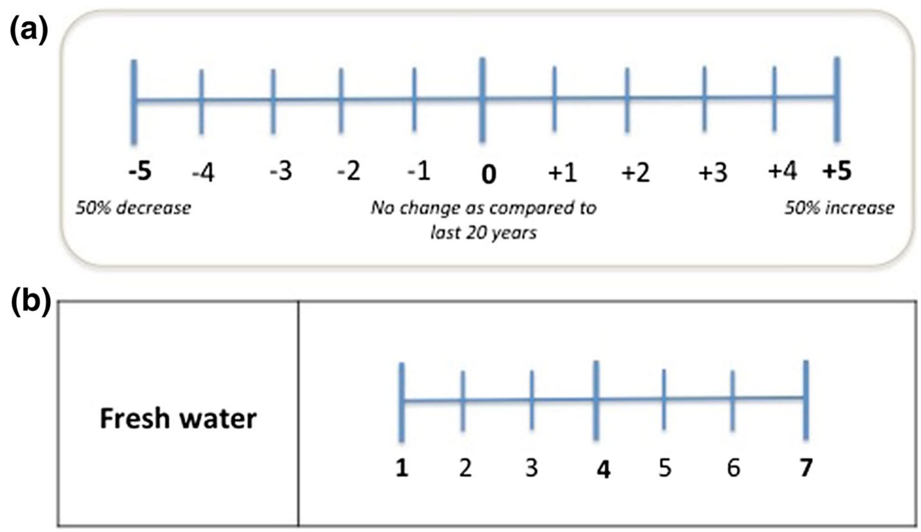

Fig. 2 **a** Example of a scale used to elicit expert judgments on drinking water outcomes. **b** Example of scale used to elicit expert judgments on extent/importance of ES provision under different scenarios

Landowner compensation costs in the 2004 estimates were subtracted from the 2004 total project cost, but added to the 2012 value calculation, based on current estimates from SANAA experts. The resulting figure was divided by the basin volume and projected infrastructure lifespan (25 years) resulting in a unit value of $0.16/m^3 (2012 dollars). In effect, the watershed management project can be viewed as marginally delaying theses incremental storage costs, which will be borne when the new reservoir project is completed. Third, the incremental water estimated to be available in summer months due to the watershed management plan was valued using a direct measure of consumer willingness to pay (WTP), as represented by the price per volume presently paid by inhabitants of marginal neighbourhoods in Tegucigalpa who purchase water from cistern trucks belonging to private distributors (Vignola et al. 2015). Pond et al. (2011) suggest that social cost benefit analysis and shadow pricing are appropriate ways to value water provision in water scarce circumstances. In this case, consumer WTP reflects what currently occurs in Tegucigalpa in the face of severe water shortages: water cistern trucks belonging to both SANAA and private commercial enterprises distribute water to marginal neighbourhoods. Water from SANAA trucks is distributed freely while the commercial trucks purchase water from SANAA at a reported rate of 0.05 Lempiras/gallon and resell to households. Coello Balthasar (2011) shows up to 800,000 m^3 of water being commercialized in Tegucigalpa by private cistern trucks.[3] Contemporary media reports on the cost to consumers of water from private cistern trucks were used to estimate consumer WTP. The reported rates were converted to 2012 dollars and cubic metres and then averaged.[4]

The values resulting from the calculation of each of the three variables were summed to reach an estimate of the annual value of full benefits expected in the year 2030 when maximum benefits are achieved from the watershed management plan. However, since some benefits will accrue upon immediate completion of the management plan (from control of soil erosion control due to measures applied to agricultural fields), 60% of these benefits were assumed to accrue in as early as 2019 and increase in a linear fashion over the net 11 years, reaching 100% in 2030. While this assumption is arbitrary, it was implicit in the views of the experts interviewed.

3.2.6.2 Net present value calculation Net benefits (benefits minus costs) were calculated for the period 2013–2035, using three different discount rates for Honduras as calculated by Lopez (2008). To determine NPV, economic costs and benefits had to be distributed over the period under evaluation (2013–2035). A time horizon for the 2013–2035 period was constructed in Excel with the costs of watershed management plan implementation reflected for the implementation period (2013–2018) and the benefits resulting from plan implementation reflected

[3] It was decided that either the consumer purchase price or the total cost of the SANAA program would be possible proxies for water value and that the more expensive of the two values would be more representative of true cost. However, SANAA officials reported having no measure of the cost of their cistern truck water distribution program and the sale price to private trucks was considered to very likely to under-represent true value given the utility's interest in getting water to the population.

[4] Prices reported in 2012 were considered 2012 Lempiras. Prices quoted in 2011 were considered 2011 Lempiras. In this second case, 2011 Lempiras were converted to 2012 Lempiras using the change in the Honduran Consumer Price Index between those 2 years (1.051). 2012 Lempiras were converted to 2012 dollars using the exchange rate applied in this study of Lps. 19.80.

during the subsequent period (2019–2035). The projected costs of the watershed management plan were adjusted to 2012 dollars and transfers (namely taxes) and other zero opportunity cost items (e.g. local physical labour) were removed from the cost calculation, in keeping with benefit/cost principles. The result was a cost in 2012 dollars for each of the 6 years over which the watershed management plan will be implemented (2013–2018). In order to distribute benefits over the corresponding period, it was assumed that some benefits will start to accrue upon implementation of the watershed management plan, while others will take time to materialize. For example, the management scenario assumes 2000 ha of agricultural fields under soil conservation measures. These benefits will materialize immediately. Conversely, benefits from the reforestation activities (on approximately 1500 ha) are assumed to materialize more slowly as the forest matures. Thus, it was initially estimated that 60% of the benefits will materialize in 2019 and that benefits will increase in a linear fashion up to 100% in 2030 when benefit provision will stabilize. This distribution of benefit provision over time reflects the substantial area under soil erosion management as compared with the area that will be reforested. Thus, the total annual economic benefit described in the previous section was ascribed to the year 2030 and to each subsequent year up to and including 2035 and 60% of that benefit was ascribed to the year 2019 and a compound growth rate of 1.0475 was applied to calculate the value for each year from 2020 to 2030. This calculation was carried out for both the high and low climate change scenarios. The NPV was calculated using the Net Present Value (NPV) function in Excel. Finally, sensitivity testing was applied to test the influence of three assumptions and estimations on the NPV calculation: future water yield under climate change, proportion of benefits accruing in 2019, and proportion of existing accumulated sediment in reservoir attributable to Hurricane Mitch (and relevant to lost storage capacity).

4 Results in terms of the judgment findings

4.1 Drinking water infrastructure variables and NPV

Beginning with the forecast of specific watershed impact variables, under the low climate change scenario, sediment accumulation in the reservoir is expected to be reduced by 18% (unimodal response), turbidity levels in the reservoir are expected to be reduced by 24% (unimodal response), dissolved oxygen levels in the reservoir during the annual dry season are expected to increase by 7% (bimodal response), and water inflow into the reservoir during the annual dry season is expected to increase by 11% (bimodal response). Under the high climate change scenario, sediment accumulation in the reservoir is expected to increase by 13% (unimodal response), turbidity levels in the reservoir are expected to increase by 10% (unimodal response), dissolved oxygen levels in the reservoir during the annual dry season are expected to increase by 24% (unimodal response), and water inflow into the reservoir during the annual dry season is expected to increase by 29% (bimodal response). The annual benefits of these changes in terms of the value of improvements in water provision (quality and quantity) are described in Table 6. As can be seen, significant benefit comes from the projected additional water in the dry season (base flow) and there are negative benefits related to projected increased erosion and turbidity under the high climate scenario.

The overall estimate of the NPV of the stream of future benefits, expressed as a lump sum for the year 2012, in 2012 US dollars is shown in Table 7. The results of sensitivity testing show that overall benefit derived from the watershed management plan is highly influenced by overall water yield (almost 100% of the benefits are derived from future water yield), and is also influenced by how early (or late) benefits occur, but is not affected by the accumulated sediment assumption.

Overall, the study points to significant economic benefit from the watershed management plan for the water utility (and thus society as a whole) through its contribution to achieving basic water provision objectives. Net economic benefit in 2012 ranges from $29 to $76 million dollars (2012 dollars) depending on the climate change scenario and assuming the median social discount rate of 3.3%. Net economic benefit increases if benefits materialize earlier, rather than later, which is an incentive for the water utility to act early in ways that increase base flow and limit upstream soil erosion. As shown in Table 6, benefits are primarily derived from increased water yield, which experts expect to result from reforestation activities. The experts all assume that forest cover has a positive

Table 6 Annual benefits generated by the watershed management plan for the years 2030–2035 expressed in undiscounted 2012 dollars

Variable	Low climate change scenario	High climate change scenario
Storage volume	$1000	−$6000
Additional water	$35,220,000	$40,821,000
Water quality	$129,000.00	−$24,000
Totals (rounded)	$35,351,000	$40,791,000

Table 7 NPV of the net economic benefit of the watershed management plan to the national water utility in 2012, expressed in 2012 dollars, by social discount rate and climate change scenario

Social discount rate	Low climate change scenario	High climate change scenario
2.1	$34,721,000	$91,518,000
3.3	$28,580,000	$76,135,000
4.5	$23,593,000	$63,616,000

The source for the social discount rates shown in Table 7 is Lopez (2008)

relationship with base flow and the watershed management plan demonstrates a similar logic. Other studies show this pattern is not necessarily true in all cases (Locatelli and Vignola 2009), a point explained to the experts in the background information. Hence, the results show this is an important area for further study.

4.2 Broader ecosystem service provision

The results suggest that the watershed management plan will increase the area of the watershed providing all the important ecosystem services addressed in the study, irrespective of the climate outcome. Nonetheless, the best outcomes for the provision of fresh water, fibre and soil formation are estimated by the experts to occur with the full implementation of the watershed management plan and under the high climate change scenario. Conversely, the best outcomes for erosion control, pest and natural hazard regulation, pollination and recreation are judged to occur with the full implementation of the watershed management plan and under the low climate change scenario. The experts judged that climate change scenarios would not have any affects on nutrient cycling outcomes.

The results of the judgment task indicate the importance of the ecosystem service to wellbeing in the watershed is judged to be independent of both the management and climate change scenarios. Furthermore, no ecosystem service was considered completely substitutable. Fresh water and soil formation were considered non-substitutable by other actions and pollination and natural hazard regulation received similar values (not amenable to substitution from other sources). Fibre, fuel, nutrient cycling, erosion regulation, pest regulation and recreation were considered partially substitutable.

In summary, the watershed management plan is judged to provide positive non-market impacts for local communities in the form of increased provision of a range of important ecosystem services related to community well-being (e.g. agricultural livelihoods, natural hazard regulation). This finding increases the total economic benefit of the watershed management plan, although it was not the point of this study to quantify these benefits in dollar terms. Moreover, greater ecosystem service provision contributes to both human and ecological resilience and to human development in the watershed.

5 Discussions and conclusions

Climate change adaptation questions are wrought with uncertainties (e.g. future climate and its social and environmental impacts, performance of chosen alternatives and the needs and preferences of society in the future). They require thoughtful consideration from multiple perspectives (e.g. robustness, feasibility and relationship to climate change mitigation, sustainability or other objectives) in order to increase chances that adaptation decisions are both efficient and effective (including avoiding maladaptation) (Moser and Ekstrom 2010). Expert judgment is an important approach to characterizing impacts of policy alternatives, in order to evaluate adaptation alternatives for decision makers and civil society. Moreover, EBA is being increasingly promoted as a cost-effective, flexible and accessible alternative to costly infrastructure investments to cope with future climate impacts, especially in relation to water resources (Jones et al. 2012; Munang et al. 2013).

Computer modelling is commonly used to assess the combined effect of climate change, land use change and population growth on environmental and social outcomes (see, for example, Metzger et al. 2006 and Nelson et al. 2009). However, there are insufficient resources (both money and time) to conduct studies of similar complexity for all adaptation and resource management questions in all locations and the constraints are even greater in developing countries. Thus, simple, straightforward judgment tasks, like the one described in this paper, provide the opportunity for similar scenarios to be assessed and compared in ways that assist and enrich policy development and decision-making at relevant scales.

In this case, the use of structured judgments by technical specialists allowed for the net benefits of the watershed management plan to be estimated, by providing insight into the parameters to be measured and the future performance of those variables under specific, hypothetical climate and management scenarios. The consolidated judgments indicate significant net benefit to the water utility under a range of climates. More specifically, it is judged that the watershed management plan will perform well in terms of increased water quantity, but may not be robust enough under the high climate change scenario where greater rainfall will increase erosion despite the plan's erosion control measures.

The avoided cost of new infrastructure served as basis for estimating EBA benefits. This is a logical approach since EBA and infrastructure-based adaptation options are often mutually exclusive (e.g. mangroves or dykes as coastal protection options). The options in this case study (watershed management plan versus new reservoir in the same watershed) happen to be complementary. Nonetheless, the cost of a new reservoir represents the extent to which the water utility is willing to go to fulfil its mandate and therefore a benchmark against which the EBA alternative can be evaluated. Should the EBA alternative enable the water utility to meet its goal in terms of quality and quantity of water provision, then the reservoir becomes an avoided cost.

The economic valuation focused on the benefits accruing to the national water utility from projected increases in water yield and sediment retention, as represented by increased drinking water availability, maintenance of storage space, and reductions in treatment costs. As noted earlier, the methods involved a combination of WTP and replacement cost approaches to ecosystem service valuation. It is a marginal value approach; conversely, the value to society of avoiding dramatic change in watershed system dynamics due to unforeseen factors was not addressed (Farber et al. 2002). A consideration of the key elements and critical thresholds in the ecological system that sustains water yield and quality in the Guacerique watershed would have provided a different (and likely higher) value (Farber et al. 2002).

The additional usefulness of expert judgment in EBA approaches is the opportunity for learning. The results of the judgment exercise highlight the potential failure of the watershed management plan to meet one or more of its key objectives under more extreme climate change scenarios. The results indicate that increased precipitation that may be expected under the high climate change scenario may reduce water quality and increase water treatment costs, despite actions under the watershed management plan that aim to protect soils and reduce erosion. This surprising pattern underscores the need to seek and prioritize effective soil management practices to make the watershed management plan a more robust EBA initiative. These points are particularly important if increased precipitation manifests as a feature of future climate in the region, but also to help accommodate the impacts of extreme precipitation events under both the climate scenarios. Thus, the results indicate how to make the selected EBA management alternative more robust (prioritize interventions that minimize erosion potential) and highlight one key assumption requiring closer study (effect of reforestation on base flow). This demonstrates the ways in which expert judgment and structured elicitation processes can support informed policy decisions on EBA alternatives in the face of uncertainties and complexities related to the provision of ecosystem services.

In summary, not only did expert judgment allow for the an estimate of net benefit to be made, but furthermore, the analysis reveals how the water utility can maximize benefits and better meet their management goals, despite a changing climate. These points underline the multiple applications of judgments, as well as their importance and relevance in EBA and water resource management in pursuit of basic human development goals. They also highlight how expert judgments can be used to leverage existing knowledge and facilitate learning in resource-poor contexts where technicians and decision makers generally have limited access to relevant technical information.

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