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An uncertainty assessment framework for forest planning adaptation to climate change

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ABSTRACT

Uncertainty in forest planning is a prevailing problem affecting decision-making processes, especially those relating to climate change adaptation. Limited knowledge about uncertainty has prompted this empirical investigation of forest planners' understanding of uncertainty related to its recognition, its management and risk perception. We used a comprehensive uncertainty framework to address and test these uncertainties, with data from an online survey, to identify the views of 33 forest planners through Britain. Responses were analysed using non-parametric tests. The results showed that planners have significantly different views on uncertainty among economic, social and climatic categories. Uncertainty in the climatic category was more acutely perceived than in the economic and social categories. Planners preferred to practice active uncertainty management, as the results suggest they feel more able to manage uncertainty in forest models and their outcomes. Forest planners also indicated diverse perceptions of salient risks of change over the next 30 years. The results show they may take action only to pests, drought and wind risks posing a threat to forests even though they perceived these risks potentially to be highly regulated and controlled by forestry policies. The findings provide a better understanding of uncertainty as a source of inertia to climate change adaptation in forestry, identify new research objectives and support the development of forestry policies for climate change adaptation.

1. Introduction

In forest planning and management, uncertainty is one of the main challenges for climate change adaptation (Spittlehouse and Stewart, 2003; Spittlehouse, 2005; Ogden and Innes, 2007; Lindner et al., 2008). This issue of uncertainty has been known across scientific disciplines but with different frames and definitions. Hence, we acknowledge a rich literature identifying and defining uncertainty in a general context (Van Asselt, 2000; van Asselt and Rotmans, 2002; Walker et al., 2003; Newig et al., 2005; Brugnach et al., 2008) and in forest management (Pukkala, 1998; Kangas and Kangas, 2004; Leskinen et al., 2006; Hoogstra and Schanz, 2009; Holopainen et al., 2010). In this study we adopt the following uncertainty definition "the situation in which there is not a unique and complete understanding of the system to be managed" (Brugnach et al., 2008).

Despite the many uncertainties ever present in forest management, forest plan development cycles have progressed. However, climate change brings additional uncertainty to forest planning. We believe that this uncertainty can be a reason for inertia to climate change adaptation in forestry. Climate change uncertainty is recognized both in research (Spittlehouse and Stewart, 2003; Ogden and Innes, 2007; Bolte et al., 2009) and in forestry policies (Forestry Commission Scotland, 2006; DEFRA, 2007; Forestry Commission Wales, 2009) therefore forest planners and managers need to accept that climate change is uncertain and that they have to make decisions despite the uncertainty. However, as Ogden and Innes (2007) highlighted "uncertainties associated with climate change have discouraged forest managers from incorporating climate change into management plans".

This is an important observation, because unless climate change adaptation is implemented in forest management plans, actual change will not take place. And for researchers, such an observation raises the question whether climate change uncertainty should be different from any other type of uncertainty in forest planning. Clearly we need to focus on a decision maker's perspective of uncertainty (Gregory et al., 2006; Gabbert et al., 2010; Bijlsma et al., 2011), not on a modeller's perspective (Walker et al., 2003; Refsgaard et al., 2007; Warmink et al., 2010), because forest planning and management is about decision-making. Studies on forest planning and management have mainly addressed uncertainty from the modeller's perspective (Lindner et al., 2002; Holopainen et al., 2010) but have not addressed planners' uncertainties about for example management goals. Ignoring uncertainty about climate change in forest planning and management, i.e. beyond modelling uncertainty, can lead to a failure in adaptive forest management or inertia to climate change adaptation, and to a misunderstanding of the reasons for such failures.

As yet there is no literature that investigates the different types of uncertainty related to forest planning within a comprehensive

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uncertainty framework, although in other disciplines this has been achieved, for example, in 'technological innovations' (Meijer et al., 2006) and 'environmental modelling' (Warmink et al., 2010). As an example, (Van Asselt, 2000; Meijer et al., 2006) used a typology based on action, yield, political, model and monitoring, and goal uncertainty among others. We propose a new uncertainty analytical framework which addresses salient uncertainties from a decision-maker's perspective in forest planning and consists of uncertainty recognition, management and climate change risk perceptions.

Knowledge exists about these three components in different disciplines but this is limited in forest planning. First, uncertainty recognition studies have provided knowledge about a few types of uncertainty that appear in forest planning and management (Kangas and Kangas, 2004; Holopainen et al., 2010). However, little attention has been paid, and little empirical evidence exists of the types of uncertainty that forest planners recognize in their practice. Second, the management of uncertainty has been investigated in several studies, e.g. describing uncertainty management as active or passive in policy development (Bijlsma et al., 2011), offering strategies for dealing with diverse uncertainty types in water management (Brugnach et al., 2008) or as part of adaptive forest management approaches (Bolte et al., 2009). Although several methods for uncertainty management are available, the uncertainty of climate change relating to forest planning has not been evaluated before. Finally, many studies have investigated risk perceptions in diverse disciplines such as water and environment management (McDaniels et al., 1997; O'Connor et al., 1999), mitigation of wild fire (Martin et al., 2009), or assessment of ecological risks (McDaniels and Axelrod, 1995). Risk is important in decision-making because it may justify the necessity and intention to take action (Adger et al., 2009). However, whether or not forest planners consider risk in their management plans for climate change adaptation should depend on their individual risk perception. Yet there is a knowledge gap about what level of climate change risk perception forest planners have.

Our main objective is to investigate uncertainty in forest planning within a structured analytical framework. We address and answer the following three research questions: a) identify which types of uncertainty forest planners recognize in forest planning b) determine how forest planners prefer to manage uncertainty associated with forest models and their outcomes, and c) analyse how forest planners perceive climate change risks over time. Using a survey method, the study explores views and perceptions about uncertainty and risk in forest planning in Britain. The objects of analysis are the forest planners who decide about the future states of forests. We next describe the method for data collection, the uncertainty analytical framework and the data analysis. The subsequent section presents achieved results, and finally the last section summarizes and discusses the key findings.

2. Materials and methods

2.1. Data collection

The target population consisted of forest planners working for the Forestry Commission (FC), responsible for the management of the 812,000 ha of the national forest estate, representing 27% of the forest area in Britain with 7% in England, 4% in Wales, and 16% in Scotland (Forestry Commission, 2012). We surveyed two groups of planners, district planners who are responsible for strategic decisions at a district level and design planners who are responsible for operational decisions at a local forest block level. In addition since forestry is a devolved function in Britain, we expected forest planners to have a diverse uncertainty understanding due to different forestry policies in the three countries of Britain, i.e. England, Scotland, and Wales, which are affected by different climatic and edaphic conditions with diverse risks. Based on the research questions we selected purposive sampling (see (Babbie, 2010 p. 193)) as a suitable sampling method. The sample included all 25 forest district planners with one design planner for each district, making a total sample size of 50. In each district, a district planner randomly chose one design planner. We received in total 38 responses. After filtering out incomplete responses the response rate was 72% for forest district ($n = 18$) and 52% for forest design planners ($n = 12$), with two forest districts without design planners and three responses from planners having both roles. For the countries, the number of planners were for England ($n = 12$), for Wales ($n = 5$), and for Scotland ($n = 16$).

To collect views about uncertainty among planners we used an online survey, which has shown to be a suitable method in similar studies (Stedman et al., 2004; Bellamy and Hulme, 2011). We conducted the survey using SurveyMonkey (SurveyMonkey, 2011). The online survey method was a more practical solution for data analysis, it was easily accessible by the planners and it had the ability to effectively reach the survey group simultaneously. We pre-tested the survey with a pretesting protocol (Fowler, 1995) using four experts from Forest Research, UK and one forest planner working at a National FC Planning Office. The survey consisted of four sections: 1) statements about the recognition of uncertainty, 2) statements about the management of uncertainty, 3) statements about climate change risk perceptions, and 4) general questions about respondents. All statements were on a 7-point Likert scale. For uncertainty recognition and management the scaling ranged from strongly disagree to strongly agree, but specific scaling was used for risk perceptions (see details in Section 2.2.3). Statements included a "Don't know" option. To measure different types of uncertainty, we scrutinized statements in terms of their face and content validity. Additionally, statements were in a random order within each section to avoid leading information from the previous statements. The general section of the survey included information about job title, forest district name, length of time the respondent had worked in the current role, age category, and the highest achieved qualification. Data were collected between October and November 2011 for a period of 5 weeks, giving respondents sufficient time to fill out the survey which required about 20 minutes to complete. After the initial two weeks we sent an email reminder, which increased the response rate.

2.2. Uncertainty analytical framework

Our framework consisted of three key components. The first component was the recognition of different types of uncertainty with respect to social, economic and climatic (environmental) categories, the three pillars of sustainable forest management (Forestry Commission, 2007). If climate change uncertainty was not recognized or it was recognized differently to other types of uncertainty in forest planning and management, we would have a first indication for the inertia about climate change adaptation. The second component was about uncertainty management. If forest planners were to take a passive rather than an active attitude towards uncertainty management, we would have a second indication for the inertia about climate change adaptation. The third component was risk perception, i.e. a quantitative representation of uncertainty (Van Asselt, 2005) as perceived by forest planners. In forest planning risks are valued, interpreted, avoided, or accepted. We accept the conventional definition of risk as a combination of the hazard and the impact (Blaikie, 1994) but also expand our risk understanding to the non-technical risk definition of "intuitive judgments" (Slovic, 1987). In the following three sections we describe these components.

2.2.1. Recognition of uncertainty

A generic method for uncertainty recognition was applied (Table 1) based on the knowledge from previous studies in other domains (Van Asselt, 2000; van Asselt and Rotmans, 2002; Walker et al., 2003; Meijer et al., 2006; Brugnach et al., 2008). Table 1 presents the assessed uncertainty types along with their definitions. A set of statements addressing uncertainty in economic, social and climatic categories is in the Appendix A (Table 12). These categories represent the main problems that forest planners deal with in practice. The economic category measures the uncertainty of monetised goods and services in forestry, e.g.

Table 1
The definitions of the main uncertainty types present in decision-making processes.

Sources/dimensions of uncertainty	Uncertainty type	Definitions	References
Epistemic or limited knowledge	Action (3)[a,b,c]	"Uncertainty with respect to the composition of the set of alternative options"	Van Asselt (2000)
	Model and monitoring(2)[a,c]	"Decision-makers' doubt on the validity of the model and data sets they employ"	
	Yield(3)[a,b,c]	Uncertainty in a respect to associated costs and benefits of each alternative option	
Stochastic or variability of a system	Goal(3)[a,b,c]	"Uncertainty or ambiguity about the preferences or goals the decision-maker aims to satisfy"	Van Asselt (2000)
	Multiple knowledge frames(3)[a,b,c]	Uncertainty about knowledge frames referring to differences in views how decision-makers understand a system and how they interpret information about the system.	Brugnach et al. (2008)
	Randomness of nature(3)[c]	"the chaotic and unpredictable nature of natural processes"	Van Asselt and Rotmans (2002); Walker et al. (2003)
Level of uncertainty	Political (1)[d]	Perceived uncertainty about the effects of governmental policies	Meijer et al. (2006)
	Recognized ignorance(3)[a,b,c]	"uncertainty about the mechanisms and functional relationships being studied"	Walker et al. (2003)
	Scenario(3)[a,b,c]	Uncertainty related to a range of possible discrete outcomes.	
	Statistical(3)[a,b,c]	Uncertainty as a measurable deviation from the "truth" value.	

Notes: () — number of statements.
Categories: [a] — economic, [b] — social, [c] — climatic, [d] — no category.

timber production; the social category measures the cultural service benefits of forests to society, e.g. recreation use; and the climatic category measures the impacts of climate on the forest ecosystem, e.g. the effect of wind on forests. To provide further information to researchers and policy-makers, we classified types of uncertainty to one of the three main sources or dimensions of uncertainty (Van Asselt and Rotmans, 2002; Walker et al., 2003) i.e. epistemic uncertainty, stochastic uncertainty and level of uncertainty (Table 1). Epistemic uncertainty is due to the imperfect knowledge, stochastic uncertainty is due to natural variability and, the level of uncertainty represents the degree of limited knowledge.

A few definitions in Table 1 require a more detailed explanation. Scenario uncertainty differs from action uncertainty in that scenarios relate to the uncertain states of a system in the future whereas action uncertainty addresses complexity in the choice among alternative options. Recognized ignorance differs from multiple knowledge frames in that the former highlights the existence of uncertainty about a system under study which a decision maker omits, whereas the latter implies a decision maker has several explanations about a system with different meanings.

2.2.2. Management of uncertainty

For the investigation of uncertainty management of model and monitoring uncertainty – representing forest planners' doubt about the validity of models and their outputs – we used two categories of methods, passive and active (Bijlsma et al., 2011). When forest planners share or explore uncertainty in their planning practice they apply active methods, whereas when they ignore uncertainty they apply passive methods. To investigate this uncertainty we chose methods from (Bijlsma et al., 2011) relevant to forest planning and developed specific statements. Using the statements in Table 2 we explored how forest planners manage uncertainty about forest model characteristics and their outputs. Before providing statements to planners, a list of the five main forest models, such as Ecological Site Classification (Pyatt et al., 2001) and ForestGales (Gardiner et al., 2006) widely available to planners across Britain were given as examples in order to be clear about a forest model definition.

2.2.3. Climate change risk perception

For the assessment of forest planners' risk perceptions to climate change, previously developed judgment scales were utilized (McDaniels and Axelrod, 1995; McDaniels et al., 1997). From the original list of 31 scales we chose 6 judgment scales. The rationale for selection was based on their relevancy to: i) forest ecosystems and forest planning practice, ii) the climate related hazards studied, iii) the measurability of change to hazards studied, and iv) providing large variability across judgment scales. Practical reasons dictated the small number of scales tested, enabling planners to fill out the survey in a short time in contrast to 2–3 h in the original study (McDaniels and Axelrod, 1995). In addition, this study included one new scale of "concern" to measure the degree of worry or fear about individual hazards, since it was considered an important factor for taking action (Raaijmakers et al., 2008). The original statements of (McDaniels and Axelrod, 1995) were re-worded to better relate to forestry planning practice, the assessment of climate change risk perception, and to address change over time while considering the impacts of each hazard. Planners were asked to assess risk over a time frame of 30 years because this time period relates to the medium-term climate change impacts and is similar to the mid-rotation length of managed forest stands in Britain. In order to assess risk perception based on our risk definition, all statements included the words of "the impacts" and the hazards. Table 3 summarizes judgment scales and shows statements with the corresponding Likert scaling. The hazards under investigation were drought, fire, frost, pests, water-logging and wind because they represent the major hazards already affecting forests in Britain (Read et al., 2009).

Table 2
The management methods for dealing with model and monitoring uncertainty (methods from (Bijlsma et al., 2011)).

Methods	The sub-sequent methods	Statements
Active	Transparency	In my forest planning practice I talk about sources of inaccuracies in forest models with colleagues or stakeholders involved in forest planning.
Active	Safeguards	In my forest planning practice I work with ranges of predictions from forest models.
Active	Knowledge acquisition	In my forest planning practice I gather additional information to reduce inaccuracies from forest models.
Active	Establishing best available knowledge	In my forest planning practice I discuss contested knowledge about assumptions within forest models with colleagues or stakeholders involved in forest planning.
Passive	Recognized ignorance	I am aware of inaccuracies in forest models but I do not incorporate these inaccuracies into my forest planning practice.
Passive	Avoidance	In my forest planning practice I change objectives of forest design plans when forest models are inaccurate.

2.3. Data analysis

In the analytical framework we assessed uncertainty through the different constructs (e.g. active uncertainty management) related to specific statements. We ensured that each construct was unidimensional and reliable. The measure of a construct was highly unreliable if based only on one statement because the level of random error the statement explains was unknown (Zeller and Carmines, 1980). However, a composite measure consisting of statements provided a more reliable representation of a construct, which we assessed with Cronbach's alpha. First, to ensure that each composite measure was unidimensional, i.e. representing only one construct, we used a principal component analysis (PCA) with an unrotated matrix. The PCA shows the highest explanatory variance of the 1st factor — representing the composite measure (Zeller and Carmines, 1980; Hunter and Rinner, 2004). For composite measures we used only representative statements with high factor loadings (ideally > 0.7 but also >0.6 were considered for further analysis), because of the small sample size (Field, 2009). In addition, the statements needed to meet the constraint of inter-item-correlation between 0.3 and 0.9, to avoid problems of collinearity (Field, 2009). Second, for the reliability and consistency of composite measures consisting of several statements, Cronbach's alpha was used (Zeller and Carmines, 1980; Field, 2009). The acceptable Cronbach's alpha value for measures should be above 0.6 (O'Connor et al., 1999) or 0.7 (Field, 2009) and values ≥ 0.7were used in our analysis. For the statistical analysis all responses from planners were summed for statements representing a single composite measure e.g. uncertainty in the economic category. For example, the economic category consists of three statements thus the range of values was from 3 to 21, with low values representing certainty whereas high values indicating uncertainty about economic issues, and values around 14 representing a neutral perspective.

Using non-parametric tests we tested the differences in the views on uncertainty for the whole sample of planners then between the two types of planners — district and design, and finally we tested for differences among all planners in each of the three devolved countries of Britain (England, Wales, and Scotland). We used these tests because of the small sample size and data in some cases did not meet the assumption of normality (Field, 2009). For the assessment of differences between two independent groups of district and design planners, the Mann–Whitney test was used which ranks the summed response data. For the assessment of differences among all planners and three independent groups of planners within three countries, the Kruskal–Wallis test was used (Gibbons, 1993; Field, 2009). For all composite measures we stated the null hypothesis (H_0):'there is no difference in uncertainty perspectives between planners or among countries'. And the alternative hypothesis (H_1) tested: 'there is a difference in perspectives on uncertainty, first between types of planners and secondly among all planners within three countries'. Finally, we used the Shapiro–Wilks test for normality testing of the composite measures (Field, 2009), which for some measures confirmed a non-normal distribution. Responses from four planners were excluded from the statistical analysis of the risk perception due to the inconsistency of their answers, which included a majority of 'Don't know' responses. We used the R 2.13.1 statistical programme (R Development Core Team, 2011) with the statistical package "psych"(Revelle, 2011) for the data analysis, and the "ggplot2"package (Wickham, 2009) for the visualization.

3. Results

3.1. Recognition of uncertainty

The composite measures used for the recognition of uncertainty which met the criteria of unidimensionality and acceptable internal consistency are shown in Table 4. Only a small number of statements from the total number met these criteria, except for the randomness

Table 3
The judgment scales with statements used in the survey for measuring climate change risk perceptions.

Judgment scale	Statements[b]	Scaling[c] (7 point Likert scale)
Ability of nature to adapt[d]	…How will the forest's natural adaptive capacity to the impacts of these hazards change?	1 - Strongly decrease to 7 - strongly increase
Concern	…How will your concern about the impacts of these hazards change?	1 - Strongly decrease to 7 - strongly increase
Ability to regulate	…How much more or less will Forestry Commission policies which regulate the impacts on forests for these hazards change?	1 – Much more to 7 – much less
Controllability[d]	…How will forest design planning ability to control the impacts on forests for these hazards change?	1 - Strongly decrease to 7 - strongly increase
Frequency[a]	…How will the frequency of impacts on forests from these hazards change?	1 - Strongly decrease to 7 - strongly increase
Scope	…How will the extent of the forested area affected by these hazards change?	1 - Strongly decrease to 7 - strongly increase
Predictability[d]	…How well can the impacts of these hazards be predicted?	1– Not at all to 7 – very well

a —Originally this scale was called "Duration" in (McDaniels and Axelrod, 1995) but for forestry and studied hazards "Frequency" is more appropriate.
b —In the survey all statements started with "In the next 30 years in your forest district …".
c —"Don't know" was the 8th option in the survey.
d —Judgment scales with reversed scaling.

Table 4
Measures representing different types of uncertainty, with number of used statements and Cronbach's alpha representing internal consistency.

Measures	Number of selected statements[a]	Cronbach's alpha
Uncertainty types: randomness of nature	3 (3)	0.75
Category: economic	3 (8)	0.74
Category: social	5 (7)	0.78
Category: climatic	4 (10)	0.73
Sources of uncertainty: epistemic	5 (8)	0.70
Sources of uncertainty: stochastic	4 (10)	0.73

Classification of statements into measures is in Appendix A (Table 13).
a () — Number of all statements.

of nature measure which includes all of them. The Cronbach's alpha values ≥ 0.7 indicate acceptable internal consistency of used statements.

Table 5 shows results that indicate a very significant difference in uncertainty recognition among economic, social, and climatic categories for all planners $H(2) = 22.2$, $p < .001$, with their median values 4, 2, and 5, respectively. This suggests that planners understood uncertainty for each category differently, with the climatic category being more uncertain and the social category being less uncertain.

Uncertainty recognition by forest design and district planners was mostly the same (Table 6). The only significant difference between their uncertainty recognition was within the social category. For this category we rejected the H_0 and accepted H_1 saying that there is a significant difference between design and district planners in their uncertainty recognition for social issues related to forest recreation, $U = 47$, $p < .01$. In addition, the median values for design (2) and district (3) planners indicated a lower recognition of uncertainty for the social category. The 25th and 75th percentiles for design (2, 2) and for district planners (2, 5) for the social category suggested a higher level of uncertainty agreement for design, but a lower level for district planners. For other measures the null hypotheses were not rejected suggesting no difference between planners' uncertainty recognition. Higher uncertainty recognition occurred only for the randomness of nature and climatic category.

The results did not reveal significant differences among countries in the planners' recognition of uncertainty (Table 7), thus we could not reject the H_0. The results indicate a higher recognition of uncertainty for randomness of nature and climatic category and greater certainty about the social category, as well as epistemic and stochastic uncertainty.

From a statistical perspective, it was unreliable to combine the majority of statements into composite measures of uncertainty due to the high variability of uncertainty among categories and the low consistency of measures indicated by Cronbach's alpha. Therefore, the responses for the five highest and the five lowest median values representing uncertainty recognition for specific uncertainty types are shown in Table 8. The highest uncertainty recognition occurred for the economic ([a]) and climatic categories ([c]), contrary to less uncertainty or greater certainty related to social issues ([b]).

Table 5
Comparison of responses for uncertainty recognition among economic, social, and climatic categories for all forest planners.

Measures for categories	All forest planners [median value][a,b]
Economic	4 (3, 6)***
Social	2 (2, 4) ***
Climatic	5 (3, 6) ***

Level of significance: * $p < 0.5$; ** $p < 0.01$; *** $p < 0.001$.
a Seven-point scale: 1 = strongly recognize certainty, 7 = strongly recognize uncertainty.
b —():Values represent the 25th and 75th percentiles for responses.

3.2. Management of uncertainty

The statements for active uncertainty management provided a reliable measure for model and monitoring uncertainty, but passive statements did not. The measure of active management based on four statements (see Table 2) had a very high internal consistency (Cronbach's alpha = 0.89). The results in Table 9 show no significant difference in active management among forest planners or across the three countries, hence we could not reject the null hypotheses. All planners indicated a higher active management of uncertainty with median values from 5 to 6 meaning that they "slightly agree" or "agree" with active methods. The variability of responses, represented by 25th and 75th percentiles, was small with values close to the medians except for planners in England, where results show a wider range of planners' opinions from disagreement to agreement about active uncertainty management (Table 9).

For the passive uncertainty management, results for the two individual statements suggest that forest planners were either not passive or not sure about the passive management (Table 9). Planners mostly disagreed with a recognized ignorance statement suggesting an active management method. Only in England did planners indicate slight agreement for recognized ignorance. The results for an avoidance management method showed overall neutrality and also a diversity in opinions among planners and among countries. Design planners appeared to be slightly more passive, and district planners were slightly less passive about uncertainty management. Results among countries showed that planners in Wales favoured slightly more passive management, with more neutral management in Scotland, and more active management in England. In summary, the results suggest that planners are inclined to pursue active uncertainty management of forest models and their outputs and they have no strong tendency to passive management.

3.3. Climate change risk perception

Forest planners' climate change risk perceptions measured as a change from the current situation over the next 30 years differ depending on the judgment scale used (see Table 3) and the risks assessed. Our results in Fig. 1 show this variability, with partial overlay of symbols representing individual risks. Higher risk perceptions were for "concern" and "frequency" judgment scales, very high values for pests (6, 6), and high values for drought (5, 5) and wind (5, 5) hazards. On the other hand, lower risk perceptions were for the same hazards but on the "ability to regulate" and "controllability" judgment scales. This is a surprising finding — that planners perceive the same hazards on the one hand with high concern and thus higher risk but, on the other hand, with a high level of regulation through forestry policies and thus lower risk. Hence, we decided to investigate this further and show results only for drought, pests and wind which planners perceived of higher risk.

No significant differences in climate change risk perceptions were seen between design and district planners (Table 10). This means that the planners' decision-making at different management levels does not affect their risk perception. The results also show a high consistency in the planners' risk perceptions, mostly with a small deviation from the median, measured by 25th and 75th percentiles. Only for pests and the "ability of nature to adapt" scale did risk perceptions range from lower to higher risk, suggesting planners were not sure how forest management can adapt to pest impacts.

A significant difference in the forest planners' risk perception occurred among England, Wales, and Scotland on the "concern" scale for drought (Table 11). The H_0 was rejected and H_1 was accepted suggesting significant differences in the planners' drought risk perception across the three countries, $H(2)$, $p < .05$, with the median values for England (5 — higher risk), Wales (5 — higher risk) and Scotland (4 — no change). For this scale results showed a higher consistency of drought risk perception for England and Wales (5 to 6) and a lower consistency for Scotland (3 to 5), measured with the 25th and 75th percentiles. It suggests that for climatic conditions related to drought, with England being warmer and drier, this might influence the planners' perceptions about the future drought risk. The consistency of risk perception, for most scales, is high with small deviations from the median values. However, higher deviations greater or equal to 3 points, suggesting a low degree of agreement among planners, occurred for pests in Scotland and Wales on the "ability of nature to adapt", "controllability", "scope" and "predictability" scales.

For the selected judgment scales we show spatially the district planners' risk perceptions of drought, pests and wind (Fig. 2). In the visualization we excluded responses from planners who did not want to be identified. The maps show a high perception of risks on the "concern" scale for all hazards, very high for pests, in the western part of Britain. Higher risk perceptions for all hazards on the "frequency" scale are in Scotland and Wales, with a rather low response rate in England. Only in two districts in south-west Scotland did planners indicate a lower drought risk on both the "concern" and "frequency" scales. On the "ability to regulate" and the "controllability" scales planners have a lower risk perception (Fig. 2). On the "ability to regulate" scale planners perceived pest risk as very high, especially in Scotland, and no clear indication of lower or higher drought or wind risk in England and Wales. This means that planners think that regulation through forestry policies will help to reduce the impact of pests in the next 30 years in Scotland. On the "controllability" scale, planners perceived lower wind risk across Britain and for drought and pests lower risk in England and Wales but with no change or slightly higher risk for pest control in Scotland. These findings suggest that in each forest district, planners might manage risks differently.

4. Discussion and conclusions

This study has investigated the forest planners' degree of uncertainty recognition across Britain, the uncertainty management strategy preferred, and which climate change related risks perceived important. No previous studies have investigated uncertainty within forest planning in such detail. We discuss each of these three topics before drawing conclusions about uncertainty in forest planning.

4.1. Recognition of uncertainty

From the set of 27 statements classified into economic, social and climatic categories and the 10 uncertainty types, we have derived 6 composite measures of uncertainty. From the responses of 33 forest planners our statistical analysis of these measures revealed a significant difference between forest planners' recognition of uncertainty in economic, social and climatic categories, with planners being less uncertain in economic and social categories than in the climatic category. This observation is surprising as the scientific literature claims that the climate system is more predictable and less uncertain than economic or social systems (Adger et al., 2009). From all measures planners recognized only high uncertainty about the climatic category and the randomness of nature, which are possibly a cause of inertia to climate change adaptation in forest planning. Consequently, planners may opt for less uncertain forest management options (Pukkala, 1998) which consider more certain economic and social development opportunities but do not consider uncertain climate change futures. We could not find significant differences in uncertainty recognition of different measures between district and design planners with the exception of the social category, and no difference among planners across England, Wales, and Scotland. Therefore, the level of management, either operational or tactical (Forestry Commission, 2007), does not influence a

Table 6
Differences in recognition of uncertainty between design and district planners.

	Uncertainty type[a, b]	Categories for uncertainty[a, b]			Sources of uncertainty[a, b]	
	Randomness of nature	Economic	Social	Climatic	Epistemic	Stochastic
Design planners	5 (3, 6)	4 (3, 5.75)	2** (2, 2)	5 (4, 6)	3 (2, 5)	3 (2, 5)
District planners	5 (3, 6)	4 (3, 6)	3** (2, 5)	5 (4, 6)	3 (2, 5)	3 (2, 6)

Level of significance: * $p < 0.5$; ** $p < 0.01$; *** $p < 0.001$.
[a] Seven-point scale: 1 = strongly recognize certainty, 7 = strongly recognize uncertainty.
[b] —():Values represent the 25th and 75th percentiles for responses.

Table 7
Differences in recognition of uncertainty for forest planners among England, Wales, and Scotland.

	Uncertainty type[a, b]	Categories for uncertainty[a, b]			Sources of uncertainty[a, b]	
Country	Randomness of nature	Economic	Social	Climatic	Epistemic	Stochastic
England	4 (2, 5)	5 (4, 6)	3 (2, 5)	4.5 (2, 6)	4 (3, 6)	5 (3, 6)
Wales	5 (4, 6)	3 (3, 4.5)	2 (2, 3)	5 (4.75, 6)	3 (2, 5)	3 (1, 6)
Scotland	5 (4, 6)	4 (3, 6)	2 (2, 4)	5 (4, 6)	3 (2, 5)	3 (2, 5)

Level of significance: * $p < 0.5$; ** $p < 0.01$; *** $p < 0.001$.
[a] Seven-point scale: 1 = strongly recognize certainty, 7 = strongly recognize uncertainty.
[b] —():Values represent the 25th and 75th percentiles for responses.

planner's uncertainty recognition, and despite different forestry policies and different climate conditions in the three countries, planners had a similar recognition of uncertainty.

Our findings also show a high variability in the planners' recognition of different types of uncertainty represented by individual statements and within each of the categories. Furthermore, in most cases each uncertainty type had a distinct meaning within a category thus their combination into composite measures does not provide a reliable measure of uncertainty. The consequences and benefits of knowing about which uncertainty types, measures or even statements are more uncertain than others can affect the planners' selection of suitable adaptive forest measures. For example planners were very certain in their recognition of the social category statement relating to management practices on recreational use, but they were very uncertain in the climatic category assessment of soil moisture variability. This means that they know a lot about how people use forests but very little about how soil moisture variability affects forests. Knowing about which type of uncertainty forest planners consider or know about within economic, social and climatic categories should help forest policy-makers to prioritize, avoid, accept or better communicate specific uncertainties in policy documents, especially for climate change adaptation.

Table 8
The responses from all planners showing the statements with the five highest and the five lowest median values.

Rank	Statements	Median response values[d,e]	Type of uncertainty
1st	The measured standing timber volume and harvested volume is not the same.	6 (5, 7)	Statistical [a]
2nd	Soil moisture variability strongly affects my forest design planning.	6 (5, 6)	Randomness of nature [c]
3rd	In my planning practice I consider different future timber demands.	6 (5, 6)	Scenario [a]
4th	I know the full cost for a coupe rotation in advance. [r]	6 (4, 6)	Yield [a]
5th	Wind variability strongly affects my forest design planning.	6 (4, 6)	Randomness of nature [c]
23rd	Among stakeholders involved in forest planning in my district, there is no consensus about how forests are used for recreation.	2 (2, 4)	Multiple knowledge frames [b]
24th	I know what the benefits are of forest adaptation measures to extreme weather events. [r]	2 (2, 3)	Yield [c]
25th	It is difficult to choose forest management options suitable for recreation use.	2 (2, 3)	Action [b]
26th	I am aware of different objectives that local key stakeholders have for the forests. [r]	2 (2, 2)	Goal [b]
27th	I know the effects of forest management practices on recreational use. [r]	2 (1, 2)	Yield [b]

Category: [a] — economic, [b] — social, [c] — climatic.
[d]Seven-point scale: 1 = strongly recognize certainty, 7 = strongly recognize uncertainty.
[e] — ():Values represent the 25th and 75th percentiles for responses.
[r] — A statement with a reversed scale.

Table 9
Differences in active and passive management of model and monitoring uncertainty by planners and by countries, with composite measure for active management.

Active/passive management methods	Design planners[a,b]	District planners[a,b]	England[a,b]	Wales[a,b]	Scotland[a,b]
Active: composite measure	*5.5*	*5.5*	5	6	5
	(>4, 6)	*(5, 6)*	(2, 6)	(5, 7)	(4, 6)
Passive: Recognized ignorance (statement)	4	3	4	2	3
	(2, 4)	(3, 4)	(4, 5)	(1, 3)	(2.5, 4)
Passive: Avoidance (statement)	*4*	*4*	4	4	4
	(4, 5.5)	*(2, 5)*	(2, 4)	(4, 6)	(3, 5)

Level of significance: * $p < 0.5$; ** $p < 0.01$; *** $p < 0.001$.
[a] Seven-point scale: 1 = strongly disagree, 7 = strongly agree.
[b] –(): Values represent the 25th and 75th percentiles for responses.

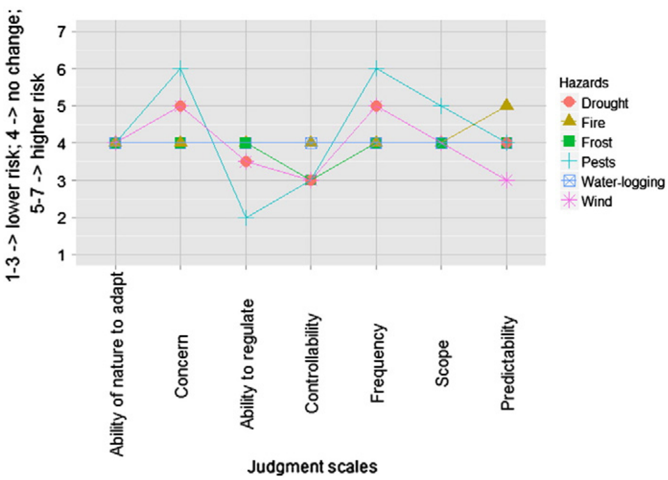

Fig. 1. Hazards profile based on median values showing changes in risk perceptions over the next 30 years for the judgment scales, responses from 33 forest planners.

4.2. Management of uncertainty

From the active and passive management methods of model and monitoring uncertainty related to forest models and their outputs, forest planners were inclined to active management and did not indicate clear support for, or against, passive management. We found no significant differences in active uncertainty management between district and design planners or among planners across all three countries. This active management attitude is promising for the development and implementation of new forest models that include climate change uncertainty, for example using new probabilistic climate change projections (UKCP09) (Murphy et al., 2009). We would then expect active uncertainty management in forest planning by means of forest models and Decision Support Systems to support climate change adaptation. However, we only investigated the management of model and monitoring uncertainty. Planners might manage other types, such as goal and action uncertainty, differently. To conclude, our findings indicate that the planners' attitudes towards uncertainty management should not be considered as a source of inertia for climate change adaptation.

4.3. Climate change risk perception

The perception relating to changes in climate risks over the next 30 years varied greatly among planners both on seven individual judgment scales and six climate related hazards, indicating planners have a broad risk understanding. Forest planners do not expect changes for fire, frost and waterlogging risks but major changes for drought, pests and wind risks. Less concern was implicit for changes in fire, frost and waterlogging, and might be explained by the low visibility of their impacts in British forests (Read et al., 2009). Whereas the evidence and high visibility of drought, pests and wind impacts (Ray, 2008; Read et al., 2009; Ray et al., 2010) possibly explain planners' higher concern for these hazards.

Only for drought did we find significant differences in the planners' perception of changing risk among countries on the “concern” judgment scale. Hence, a higher perception of drought risk change in England and Wales is more likely a reason for taking action in

Table 10
Changes in climate change risk perception from the current situation over the next 30 years for design and district forest planners.

Hazards	Judgment scales[a]							
		Ability of nature to adapt	Concern	Ability to regulate	Controllability	Frequency	Scope	Predictability
Drought	Design planners	5	5	3	4	5	4	3.5
		(4, 5)	(4, 6)	(2, 4)	(3, 5)	(4, 6)	(3, 5)	(3, 4.75)
	District planners	4	5	3.5	3	5	4	4
		(3, 5)	(4, 5)	(3, 4)	(3, 4)	(4, 5)	(4, 5)	(3, 5)
Pests	Design planners	3	6	3	3	6	5	3.5
		(2, 6)	(5, 6)	(2, 4.5)	(2, 4)	(5.5, 6)	(4, 6)	(3, 4)
	District planners	6	7	2	3	6	5	5
		(3, 6)	(5.5, 7)	(1, 3)	(2, 4)	(5, 7)	(3.75, 6.25)	(3, 6)
Wind	Design planners	3	5	3.5	3	5	4	3
		(3, 5)	(4, 5)	(3, 4)	(3, 3)	(4.5, 5.5)	(4, 5)	(3, 4)
	District planners	4	5	3	3	5	4	3
		(4, 5)	(4.75, 6)	(3, 4)	(2.75, 3.25)	(5, 6)	(4, 5)	(3, 5)

–(): Indication of the 25th and 75th percentiles for responses to a particular judgment scale.
[a] Seven-point scale: 1 to 3 = lower risk, 4 = no change, 5–7 = higher risk.

Table 11
Changes in climate change risk perception from the current situation over the next 30 years for forest planners across England, Wales, and Scotland.

Hazards	Judgment scales[a]							
		Ability of nature to adapt	Concern	Ability to regulate	Controllability	Frequency	Scope	Predictability
Drought	England	3.5 (3.75, 5.25)	5* (5, 6)	3 (2, 4.25)	3 (3, 4)	5 (5, 6.25)	4 (4, 5)	4.5 (3, 6)
	Wales	4.5 (3.75, 5)	5* (5, 5)	4 (3, 4)	3 (3, 4)	5 (4.75, 5)	4 (4, 5)	3 (3, 4)
	Scotland	4 (4, 5)	4* (3, 5)	3 (3, 4)	3.5 (3, 4)	4 (3.25, 5)	4 (3, 5)	4 (3, 4)
Pests	England	3 (3, 5)	5.5 (5, 6.25)	2.5 (2, 3)	2.5 (2, 3)	5.5 (5, 6.25)	4.5 (3.75, 6)	5 (4.25, 6)
	Wales	4.5 (3, 6.25)	7 (5, 7)	2 (1.5, 3.5)	3 (2, 3)	5.5 (5, 6.25)	4 (4, 5)	3 (3, 6)
	Scotland	6 (3, 6)	6.5 (6, 7)	2 (2, 3.25)	3.5 (2, 5)	6 (6, 7)	6 (4, 7)	4 (3, 5)
Wind	England	4 (3.75, 5)	4 (4,5)	4 (3.25, 4)	3 (3, 4)	5 (4.5, 5.5)	4 (4, 5)	3 (3, 6)
	Wales	4 (4,4. 25)	5 (4, 5)	3 (2.5, 4)	3 (2, 3)	5 (4.75, 5.25)	4 (4, 4)	3 (3, 3.5)
	Scotland	3.5 (3, 5)	5 (5, 6)	3 (3, 4)	3 (3, 3)	5 (5, 6)	5 (3, 5)	3 (3, 4)

* $p < 0.5$; ** $p < 0.01$; *** $p < 0.001$.
–(): Indication of the 25th and 75th percentiles for responses to a particular judgment scale.
[a] Seven-point scale: 1 to 3 = lower risk, 4 = no change, 5–7 = higher risk.

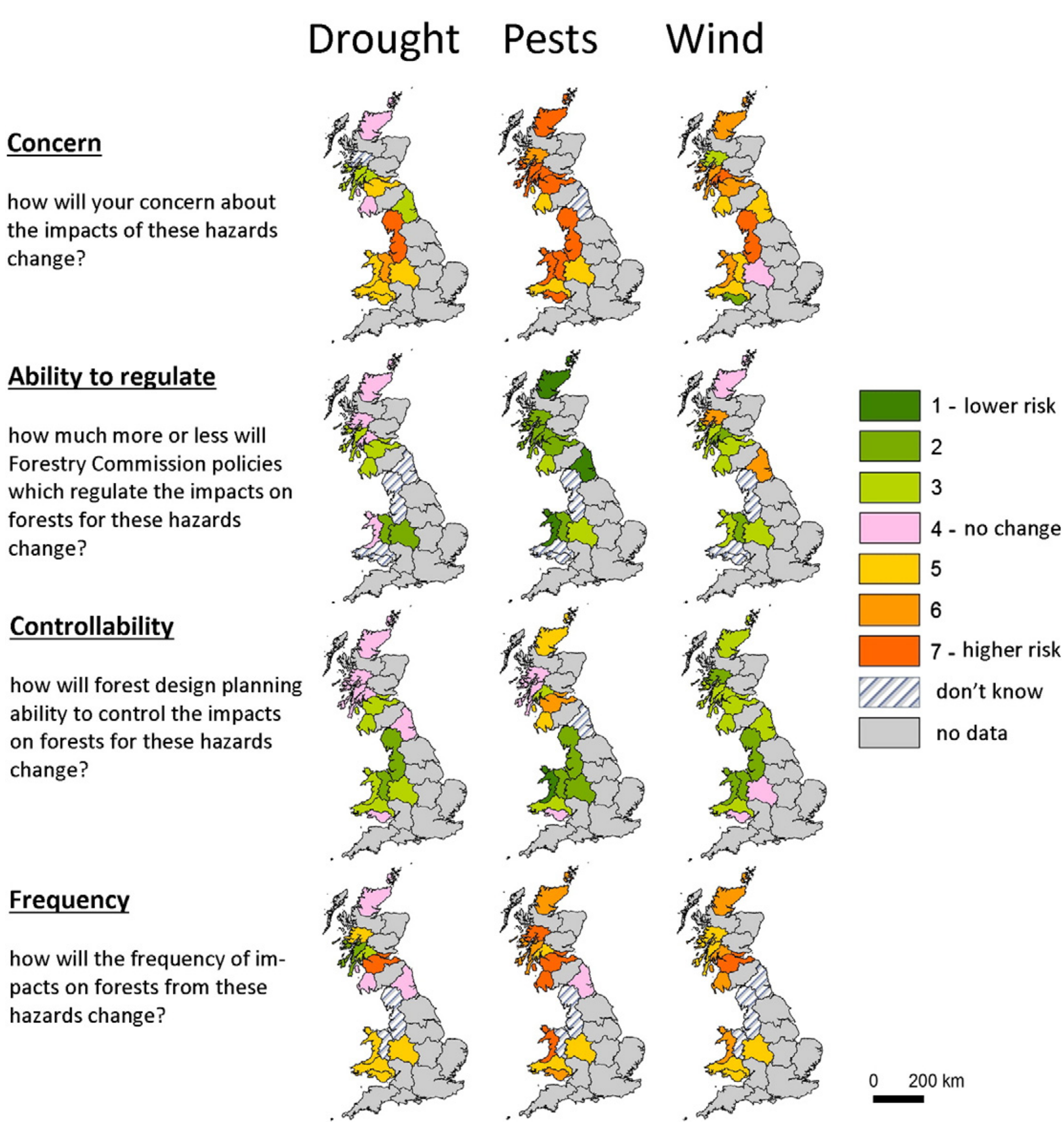

Fig. 2. Spatial differences in district planners' risk perception over the next 30 years for drought, pests and wind and four judgment scales (with the original statements).

these countries compared to Scotland, where the change of drought risk was perceived to be lower. The highest perception of changing risk on the "concern" scale is for pests followed by drought and wind, giving some urgency to address these risks in forest planning and providing an incentive for further research on the topic. On the "frequency" scale planners indicated a higher perception of changing risk of drought, pests and wind due to their increased frequency, which may affect their decisions about tree species choice and forest management systems. Studies of risk perception have concluded that due to a higher risk perception of weather events managers were keener to use the future climate forecasts in their decision-making (O'Connor et al., 2005) or to take voluntary action due to a higher perception of global warming (O'Connor et al., 1999). Hence, when planners are highly concerned about pests, drought and wind they might take action to reduce or manage these risks. In contrast, on the "ability to regulate" and "controllability" judgment scales planners perceived a lower change of risk for drought, pests and wind. A similar observation of environmental risk perceptions for different hazards (McDaniels et al., 1997) showed a higher controllability of hazards which coincided with an increased need to regulate the risks. On the one hand the planners perceived changes in risks to be controllable, regulated by forestry policies and by forest planning practice leading to an overall lower risk. On the other hand planners recognized changes in risks to be of high concern and high frequency, indicating that they may still consider drought, pests and wind to be a serious threat to British forests. It seems that the perceived need for adaptation action also depends on the location of the district managed, as our findings showed that the district planners have more diverse perceptions of changes relating to drought, pests and wind risks, probably based on the prominent issues of the districts which vary across Britain. To conclude, the ability to control and regulate the risks which planners perceived of high concern on the "concern" and "frequency" scales can be a cause for planners not to take action and is probably a key reason for inertia to climate change adaptation in forestry, since risk perception has been recognized as a reason for society to adapt (Adger et al., 2009).

4.4. Conclusions

The analytical framework has allowed us to assess the forest planners' understanding of the salient uncertainties relating to forest planning. The framework proposes a new approach to scrutinize uncertainty in forest planning that can be repeated over time or used in other disciplines if statements are substituted. The main advantages of the framework are the ability to apply, from different angles, a detailed and structured empirical analysis of uncertainty as perceived by a planner, i.e. recognition of uncertainty, management of uncertainty and changes in climate change risk perceptions. This will be useful for forestry policy development, management, and the prioritisation of research. The weak points of the study link to the low response survey rate in England, the length of the survey which possibly affected the response rate, and the potential assessment of incomplete uncertainty types present in forest planning. Our findings reveal that forest planners have a high recognition of uncertainty in the climatic category of statements, but a low recognition of uncertainty in economic and social categories. Planners prefer to promote an active management of uncertainty relating to forest models. They perceive changes in climate risks relating to pests, drought and wind to be of high concern but also highly controllable and regulative by forestry policies and forest planning. Given that uncertainty is present in forest planning, we conclude that inertia to climate change adaptation from the uncertainty perspective is mostly driven by the planners' recognition of uncertainty in the climatic category, randomness of nature, and low risk perceptions of pests, drought and wind on the "ability to regulate" and the "controllability" scales.

Appendix A

Table 12
All statements for the recognition of uncertainty.

Statements ID	Statements	Uncertainty type
S1_1	Among stakeholders involved in forest planning in my district, there is consensus about how forests provide economic benefits. [r]	Multiple knowledge frames [e]
S1_2	I find it easy to choose the cost-effective silvicultural practices from a range of options. [r]	Action [e]
S1_3	I know the full cost for a coupe rotation in advance. [r]	Yield [e]
S1_4	I trust the data from the production forecasting which I use in my planning practice. [r]	Model and monitoring [e]
S1_5	In my planning practice I consider different future timber demands.	Scenario [e]
S1_6	In my forest district timber demand is predictable for the next 50 years. [r]	Recognized ignorance [e]
S1_7	For me as a forest planner there are no doubts about the long term timber production goals. [r]	Goal [e]
S1_8	The measured standing timber volume and harvested volume is not the same.	Statistical [e]
S1_9	I know the effects of forest management practices on recreational use. [r]	Yield [s]
S1_10	It is difficult to choose forest management options suitable for recreation use.	Action [s]
S1_11	Among stakeholders involved in forest planning in my district, there is no consensus about how forests are used for recreation.	Multiple knowledge frames [s]
S1_12	The number of visits to forests obtained from surveys accurately represents the annual number of visits. [r]	Statistical [s]
S1_13	In my planning practice it is possible to know the relevant interests from all key stakeholders. [r]	Recognized ignorance [s]
S1_14	I am aware of different objectives that local key stakeholders have for the forests. [r]	Goal [s]
S1_15	In my forest district I consider different future recreation demands for forests.	Scenario [s]
S1_16	In my planning practice I do anticipate unprecedented extreme weather events.	Recognized ignorance [c]
S1_17	The choice of tree species resistant to climate change impacts is easy. [r]	Action [c]
S1_18	In my forest district the surveyed and actual number of affected trees showing symptoms of drought is not the same.	Statistical [c]
S1_19	Wind variability strongly affects my forest design planning.	Randomness of nature [c]
S1_20	I trust current outputs from Ecological Site Classification or ForestGales models for climate change adaptation. [r]	Model and monitoring [c]
S1_21	Temperature variability strongly affects my forest design planning.	Randomness of nature [c]
S1_22	The forest district strategic plan objectives related to climate change adaptation are clear for forest design planning. [r]	Goal [c]
S1_23	Given climate change, I anticipate different growth rates for each of the tree species in my planning practice.	Scenario [c]
S1_24	I know what the benefits are of forest adaptation measures to extreme weather events. [r]	Yield [c]
S1_25	Soil moisture variability strongly affects my forest design planning.	Randomness of nature [c]
S1_26	Among stakeholders involved in forest planning in my district, there is consensus about how climate change will affects forests. [r]	Multiple knowledge frames [c]
S1_27	I always know the effects of forestry policies relevant to my forest district. [r]	Political

[r] — A statement with a reversed scale.
Categories: [e] — economic, [s] — social, [c] — climatic.

Table 13
The statements used for the construction of composite scales with categories and uncertainty types.

Measures	Statements	Categories (e — economic, s — social, c — climatic)	Uncertainty types[a]
Randomness of nature	S1_19, S1_21, S1_25		
Economic category	S1_2 [r], S1_3 [r], S1_6 [r]		
Social category	S1_9 [r], S1_10, S1_11, S1_12 [r], S1_13 [r]		
Climatic category	S1_16, S1_19, S1_21, S1_25		
Epistemic uncertainty source	S1_2 [r], S1_4 [r], S1_20 [r], S1_3 [r], S1_9 [r]	e, e, c, e, s	a, mo, mo, y, y
Stochastic uncertainty source	S1_22 [r], S1_1 [r], S1_26 [r], S1_27 [r]	c, e, c, no-category	g, mu, mu, p

Note: [r] — indicates a statement with a reversed scale.
[a]: a — Action, g — Goal, mo — Model and monitoring, mu — Multiple knowledge frames, p — Political, ra — Randomness of nature, re — Recognized ignorance, sc — Scenario, st — Statistical, y — Yield.

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