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To cite this article before publication: Kristina Blennow *et al* 2020 *Environ. Res. Lett.* in press https://doi.org/10.1088/1748-9326/abc2fa

Title

The role of beliefs, expectations and values in decision-making favoring climate change adaptation – implications for communications with European forest professionals

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Abstract: Beliefs, expectations and values are often assumed to drive decisions about climate change adaptation. We tested hypotheses based on this assumption using survey responses from 508 European forest professionals in 10 countries. We used the survey results to identify communication needs and the decision strategies at play, and to develop guidelines on adequate communications about climate change adaptation. We observed polarization in the positive and negative values associated with climate change impacts accepted by survey respondents. We identified a mechanism creating the polarization that we call the 'blocked belief' effect. We found that polarized values did not correlate with decisions about climate change adaptation. Strong belief in the local impacts of climate change on the forest was, however, a prerequisite of decision-making favoring adaptation. Decision-making in favor of adaptation to climate change also correlated with net values of expected specific impacts on the forest and generally increased with the absolute value of these in the absence of "tipping point" behavior. Tipping point behavior occurs when adaptation is not pursued in spite of the strongly negative or positive net value of expected climate change impacts. We observed negative and positive tipping point behavior, mainly in SW Europe and N-NE Europe, respectively. In addition we found that advice on effective adaptation may inhibit adaptation when the receiver is aware of effective adaptation measures unless it is balanced with information explaining how climate change leads to negative impacts. Forest professionals with weak expectations of impacts require communications on climate change and its impacts on forests before any advice on adaptation measures can be effective. We develop evidence-based guidelines on communications using a new methodology which includes Bayesian machine learning modeling of the equivalent of an expected utility function for the adaptation decision problem.

Keywords: decision-making; adaptation; climate change; value polarization; expectation; blocked belief effect; tipping point behavior

Introduction

Decision-making favoring adaptation for climate change differs from one region of the world to another [1-2]. The factors influencing decisions and behaviors at the individual level are yet to be revealed [3]. Beliefs and desires (or *values*, broadly conceived) are often seen as determinants of decisions [4-5], and recently theorizing has emphasized the role of values as drivers of decision-making favoring – or, as we shall say simply, *for* climate change adaptation [6-7]. For example, the cultural cognition thesis assumes polarization occurs because individuals´ perceptions of the overall risks from climate change tend to be based on values shared with the groups with which they identify [8], and there is evidence that political and religious values affect trust in climate change communications [9].

It has been proposed that perceived adaptive capacity, including an individual´s perceived efficacy of adaptation measures and ability to carry out adaptive responses, is an important determinant of decisions about climate change adaptation [10]. Blennow et al. [11] reported variation in decision-making connected with climate change adaptation among private forest owners in a latitudinal range across European countries. They found decision-making favoring climate change adaptation to be strongly correlated with strength of belief in the local impacts of climate change and strength of belief in having experienced (the impacts) of climate change. (In this paper, we are concerned only with decision-making for climate change adaptation, i.e. intentional adaptation.) Arguably, strengthened belief that one has experienced the impacts of climate change in turn strengthens belief in the impacts themselves.

In a study of forest professionals´ (including forest advisors, planners, managers, company directors, technicians and policy makers) values of expected climate change impacts, Persson et al. [12] introduced the net of an individual´s negative and positive (expected) values. While they observed no polarization of the net value of expected impacts, they did report a trend, across Europe, in forest professionals´ net values of expected climate change impacts. Homogeneously negative expectations, especially about the impacts of sudden changes, are more abundant in South and South-West Europe and more neutral in North and North-East Europe [12].

Thus, an individual with net value of expected impacts close to zero would not expect climate change to have strong positively or negatively valued impacts, or – if (s)he expects negative as well as positive values from climate change – that the negative and positive values will cancel each other out [12]. In either of the two cases a (rational) decision-maker will expect adaptation measures to have low utility, and hence will decline to adopt those measures (unless the alternatives are even worse) [13]. The utility of measures to adapt will be higher for a decision-maker who expects stronger net, positive or negative, value; (s)he will therefore instigate adaptation.

In this paper, we conjecture that forest professionals in South and South-West Europe adopt measures designed to adapt their forest management to climate change unless they display "tipping point" thinking. Tipping point thinking occurs where "one has warranted expectations that the world, or relevant individual elements of it, have passed … into another climate system with uniformly worse consequences than the present" [12], p. 3 – i.e. that we have passed a climatic tipping point [14].

Persson et al. [12] found that tipping point thinking was common among Portuguese forest professionals. Given that some Finnish and Swedish forest professionals´ net values of expected impacts were strongly positive, we conjecture that they might find climate-change related expectations of the world, or relevant individual elements of it, warranted also for another climate system with uniformly better consequences than the present. We define tipping point behavior as behavior occurring when the net value of the expected impacts of an individual is at, or close to, the positive or negative extreme (i.e. all or almost all expected impacts are judged as always leading to uniformly good or bad outcomes by the individual, respectively), yet no measures for adaptation have been put in place.

In the survey reported here, we tested the following hypotheses, and then used the results to identify communication needs and decision strategies of European forest professionals, and to develop guidelines for adequate climate change communications (i.e. communications that the receivers need and can comprehend) [15]:

H1: value polarization correlates with decision-making for climate change adaptation (cf. [8]),

H2: strength of belief in local impacts of climate change correlates with decision-making for climate change adaptation (cf. [11]),

H3: net values of expected climate change impacts correlate with decision-making for climate change adaptation (cf. [13]),

H4: perceived adaptive capacity correlates with decision-making for climate change adaptation (cf. [10]).

Data and Methods

Data

Data were collected in a survey of forest professionals working with climate change in countries across Europe (for details of the sampling methodology, survey design, etc., see [12] and SI text S1). Approximately 10 000 forest professionals (including forest advisors, planners, managers, company directors, technicians and policy makers) were invited to participate in the survey by representatives of 10 European countries participating in the

COST Action FP 1304 network "PROFOUND" (figure 1). The questionnaire was presented in the open source LimeSurvey tool [16] and the survey was open from 22 April to 16 August 2016. Respondents responded to the questionnaire voluntarily. The data collected from researchers were not analyzed in the present study.

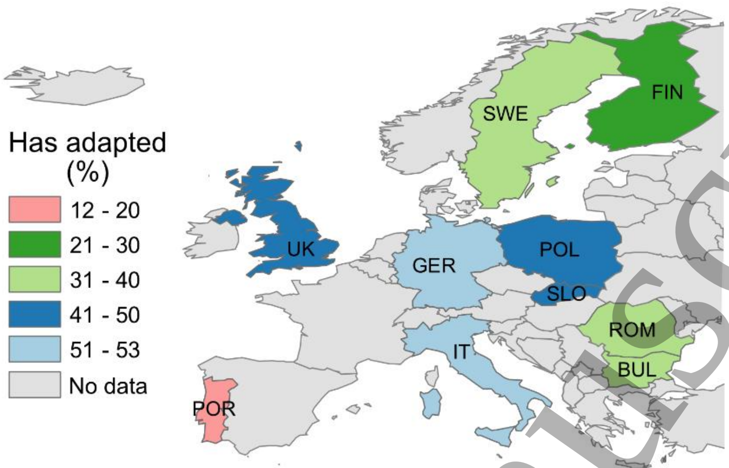

Figure 1. Percentage of forest professionals who have adapted to climate change by country. The percentage refers to those respondents who responded "Yes, always" to at least one of 15 adaptation measures proposed (Q9 in SI table S1) regarding the extent to which they actively promote those measures, thus representing the dependent variable *adaptation* in the models. BUL=Bulgaria; FIN=Finland; GER=Germany (only Thuringia surveyed); IT=Italy; POL=Poland; POR=Portugal; ROM=Romania; SLO=Slovakia; SWE=Sweden; UK=United Kingdom. Base map modified from GISCO - Eurostat (European Commission) with Administrative boundaries: © EuroGeographics © Food and Agriculture Organization of the United Nations © Turkstat.

The survey included 32 questions about climate change and forests, forest projection models and socio-demography. These were translated into the domestic languages of the respondents [12]. Responses to 11 of the 32 questions (totaling 508 complete responses) from European forest professionals were used in this study (table 1) (SI table S1).

Table 1. Short versions of the questions analyzed. See SI Table S1 for complete questions.

Number	Question	Response option
Q1	What changes* do you personally expect** from human-induced climate change on the forest in your country? Aspects: positive, negative, no***, gradual, and sudden changes.	Yes, definitely Yes, probably I do not know Probably not Definitely not
Q2	Have you personally experienced the effects of human-induced climate change on forests in your country?	Yes, definitely Yes, probably I do not know Probably not Definitely not

Q3	In your opinion, does climate change in your country lead to increasingly negative effects from sudden events (including extreme weather events) on the following: (Examples of extreme events or their impacts include: storm, fire, flooding/water logging, insect outbreak, fungus infestation, frost and drought.) Applied on 11 climate relevant objects****	Yes, definitely Yes, probably I do not know Probably not Definitely not
Q4	In your opinion, does climate change in your country lead to increasingly positive effects from sudden events (including extreme weather events) on the following: (Examples of extreme events or their impacts include: storm, fire, flooding/water logging, insects outbreak, fungal infestation, frost and drought.) Applied on 11 climate relevant objects****	Yes, definitely Yes, probably I do not know Probably not Definitely not
Q5	In your opinion, does climate change in your country lead to increasingly negative effects from gradual events on the following: (Examples of gradual climate change include: warmer or wetter climate, changes to the ground frost climate.) Applied on 11 climate relevant objects****	Yes, definitely Yes, probably I do not know Probably not Definitely not
Q6	In your opinion, does climate change in your country lead to increasingly positive effects from gradual events on the following: (Examples of gradual climate change include: warmer or wetter climate, changes to the ground frost climate.) Applied on 11 climate relevant objects****	Yes, definitely Yes, probably I do not know Probably not Definitely not
Q7	In your opinion, are the following forest management adaptation measures in your country effective for sustained timber production under climate change? Applied on 15 potential climate change adaptation measures	Yes, always Often Rarely No, never I do not know*****
Q8	Do you have the authority to implement your own ideas regarding climate change forest adaptation in your work?	Yes, always Often Rarely No, never I do not know*****
Q9	To what extent do you actively promote climate change adaptation measures, which help sustained timber production? Applied on 15 potential climate change adaptation measures	Yes, always Often Rarely No, never I do not know*****

* For clarity, the terms "effects" or "impacts" (rather than "changes") are used in the text.
** Expectations refer to the belief part of expectations, as determined by the pre-defined response options.
*** The strength of belief in the effects of climate change was taken as the inverse of the responses to this question.

**** "Sustained timber production", "Sustained pulp wood production", "Sustained biomass production for energy use", "Production of non-timber products such as mushrooms and berries", "Hunting", "Biodiversity", "Provision of outdoor recreation opportunities such as forest walks", "Storage of carbon", "Ecosystem services such as avalanche protection, clean water", "Economic gain", "Rural livelihood development".
***** "I do not know" was interpreted as meaning "I do not know" or "I am indifferent" and hence was not seen as the mid-point on the scale.

Statistical analysis and machine learning modeling
Bayesian robust correlation was used to test for correlation between negative and positive forest climate change impacts held to be true by survey respondents (henceforth we shall write simply "held true"), and the Bayesian proportions test was used to test the null hypothesis that the proportions (probabilities of success) in groups are the same, i.e. using a uniform prior distribution [17]. The variable *adaptation* was constructed from the question about the extent to which the forest professionals had advocated climate change adaptation measures which help sustain timber production (Q9 in SI table S1) (figure 1). This dichotomous variable separates respondents who had answered "Yes, always" at least once to the question about having advocated any of 15 proposed adaptation measures from those who had not.

Bayesian Additive Regression Tree (BART) models modified for classification problems, requiring no prior distribution and with the capacity to identify complex non-linear relationships [18], were fitted to the data to predict the probability of *adaptation* = 1 (SI text S2). The variables *net value of expected impacts* and *value strength of expected impacts* (homogeneity of expected climate change values and strength of expected values in [12], respectively) were constructed based on Q3–Q6 in table 1. The number of "Yes, always" or "Often" responses to the 11 objects of each of the 4 questions relating to negative/positive impacts of sudden/gradual climate change was used to determine each respondent´s valence and the strength of his or her view on climate change impacts (SI text S3). For models including the *net value of expected impacts*, the probability of *adaptation* = 1 was taken as the equivalent of the expected value of the utility of adaptation (cf. [13]).

The variable *measures* describes the availability of adaptation measures perceived to be always effective to help sustained timber production in a changing climate. It was constructed counting the number of times each respondent had answered "Yes, always" to the question on efficacy of 15 proposed adaptation measures in Q7 (table 1) and ranged from 0 to 15. *Authority* was constructed from the responses to Q8 and included the 5 factor levels "No, never", "Rarely", "Often", "Yes, always", and "I do not know" (table 1).

A five-fold cross validation was used for optimal tuning of model parameters by selecting the model with the lowest out-of-sample root mean square error [18]. Partial dependencies of covariates were analyzed using Individual Conditional Expectation (ICE) plots for visualizing the model using the ICEbox package [19]. Clusters of value objects with low *value strength of expected impacts* and groups of forest professionals were identified using Bayesian non-negative matrix factorization (bNMF) [20].

All analyses were conducted using the R Project for Statistical Computing v3.6.3 [21] using the bartMachine package [18], the ICEBox package [19], the package ccfindR [22], and the package Bayesian First Aid [17]. All of the statistical tests were made in the Bayesian statistical framework using a 95% credible interval (CI).

Results

H1: value polarization correlates with decision-making for climate change adaptation

We found a negative correlation between forest professionals´ beliefs in positive and negative impacts of climate change on the forests in their own countries (figure 2) (SI table S2) (SI text S4). This symmetrical blocking of beliefs was observed for 52% of the respondents, and it resulted in the polarization of values of climate change impacts held true at the population level as the negative and positive impacts were held true at *inverse strengths* by individual respondents (SI table S2). We call this the "blocked belief" effect.

Blocked beliefs appear to be triggered by experiences of climate change impacts (SI text S5, SI tables S3 and S5) but the estimated relative frequency of *adaptation* = 1 did not differ between those with positive and those with negative blockings (SI table S5).

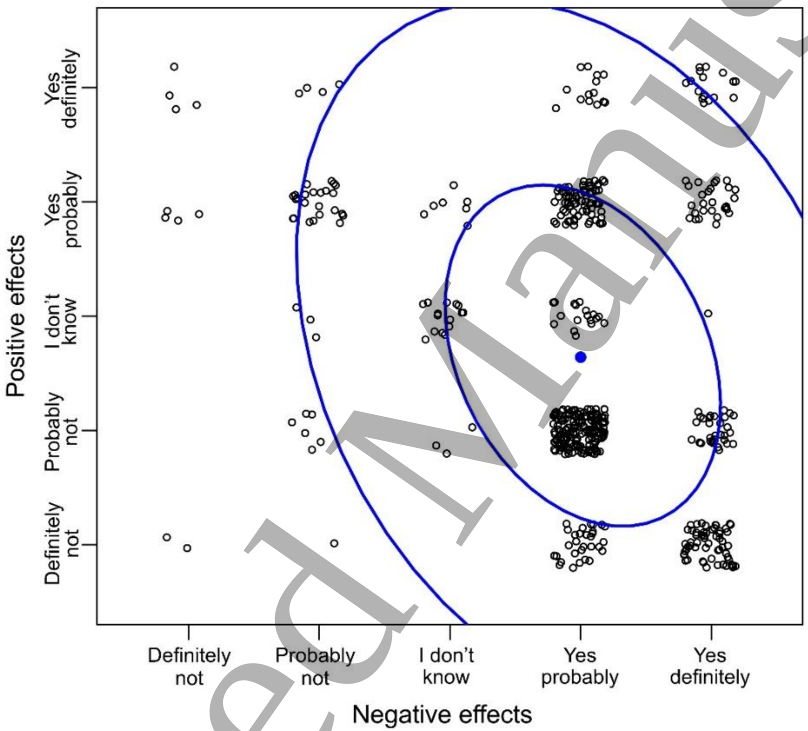

Figure 2. Blocked beliefs. Strength of belief in positive impacts of climate change on the forest by strength of belief in negative impacts of climate change on the forest (belief part of expectation in Q1, table 1). Bayesian robust correlation (ρ=-0.29; 95% CI [-0.37 – -0.21]) with inner ellipse corresponding to 50% of the observations and outer ellipse corresponding to 95% of the observations. Jittering was used to separate multiple observations of the same combination of responses to the two questions.

H2: strength of belief in local impacts of climate change correlates with decision-making for climate change adaptation

Two empirical consequences of H2 were tested: 2a) strength of belief in the local impacts of climate change on the forest correlates with decision-making for climate change adaptation (cf. [11]) and 2b) strength of belief in having experienced the impacts of climate change correlates with decision-making for climate change adaptation (cf. [11]). Although 83% of the respondents definitely or probably expected climate change impacts on the forest, not all of these had advocated taking adaptation measures (*adaptation* = 1) (Q1 in table 1). Those who held local impacts of climate change on the forest to be definitely true had advocated climate change adaptation significantly more often than those who held it to be probably true (SI table S6). However, strength of belief in local forest climate change impacts did not significantly correlate with *adaptation* in a BART model (p=0.27) (results not shown). Although 82% of the respondents believed they definitely or probably had experienced the impacts of climate change (SI table S1), strength of belief in having experienced climate change impacts on the forest correlated with *adaptation* neither in a test (SI table S6) nor in a BART model (p=0.24) (results not shown).

H3: net values of expected climate change impacts correlate with decision-making for climate change adaptation

The *net values of expected impacts* on the forest correlated with *adaptation* in a univariate BART model (SI figures S1 and S2) (SI table S7) in which the equivalent of the expected utility function for *adaptation* generally decreased with increasing *net values of expected impacts* (figure 3) (SI figure S1). This suggests that the equivalent of expected utility depended on the valence and strength of the expectations. At the negative extreme of the *net value of expected impacts* range, the model predicted more than 1 in 2 forest professionals advocating taking measures helping to sustain timber production in a changing climate, while at the positive extreme of the range, it predicted only approximately 1 in 4 forest professionals doing so (figure 3). Local minima were identified at *net values of expected impacts* close to zero, and for -70 – -55. The estimated probability of *adaptation* = 1 was lowest at *net values of expected impacts* > 37.

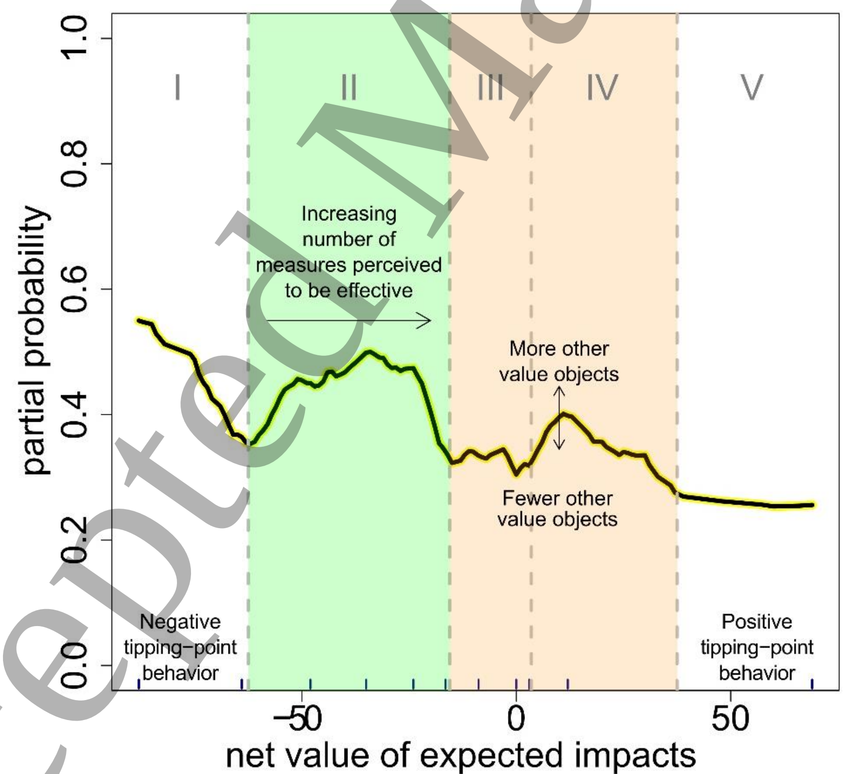

Figure 3. Decision strategies of forest climate change adaptation. Univariate BART model of the partial probability of *adaptation* = 1 based on the expected net values of climate change impacts on the forest (*net value of expected impacts*) and taken as the equivalent of the utility expected from *adaptation* = 1 (see SI figue S1 and SI table S7 for diagnostics). The main decision strategies for climate change adaptation identified from a multivariate BART model

of *adaptation* are located in Segments I-V (gray dashed lines) of the *net value of expected impact* range (see SI figure S2). Interaction with the variable *measures* occurred in the segment in green and with *authority*, interpreted as representing any forest value object expected to be impacted by climate change other than those included in Q3-Q6 (table 1), in the segments in orange.

H4: perceived adaptive capacity correlates with decision-making for climate change adaptation
Three empirical consequences of H4 were tested: 4a) the number of adaptation measures perceived to be effective correlates with decision-making for climate change adaptation, 4b) the perceived authority to implement own ideas regarding climate change adaptation correlates with decision-making for climate change adaptation, and 4c) tipping point behavior might occur for consequences both uniformly better and uniformly worse than the present. *Adaptation* correlated significantly with the *net value of expected impacts*, *measures*, and *authority* in a multivariate BART model (SI figures S1 and S2). Together, the two variables *measures* and *authority* accounted for most of the variation in the dependent variable along the *net value of expected impacts* range (compare figure 3 and SI figure S2). Interactions between the covariates created cumulative differences in fitted values of up to approximately 36% of the total range of the fitted values (SI figure S2). Local minima identified along the equivalent of the expected utility function were used as breakpoints separating the *net values of expected impacts* range into five segments for further analysis (figure 3) (SI text S6, SI figure S2, SI table S4). Negative and positive tipping point behavior was observed in the Segments I and V, respectively (SI table S8).

Communication needs
Co-clustering identified two clusters of value objects with low *value strength of expected impacts* and the respondents that best matched each cluster (SI figure S3). Groups of respondents sharing similar communication needs were identified based on the respondents' *net value of expected impacts*, *strength of expected impacts*, beliefs in and having perceived climate change impacts, and the respondents' country-belongings (figure 3) (SI text S7, SI figure S2, SI tables S4, S9-S12).

Discussion
While [12] reported no polarization of forest professionals´ net values of expected climate change impacts on the forest (*net values of expected impacts*), in the present study polarization of positive and negative values of forest climate change impacts held true (Q1 in table 1) was observed for the responses collected in the same survey (figure 2). The observed polarization at population level resulted from blocking at the individual level, by which a positive climate change impact on the forest held to be true was blocked by a negative climate change impact on the forest held true at *inverse* strengths by individual forest professionals, and *vice-versa* (SI table S2). This effect has not been previously described. We call it the "blocked belief" effect.

Blocked beliefs correlated with strength of belief in gradual and sudden impacts of climate change as well as strength of belief in having experienced the impacts of climate change (SI table S3) (SI text S5). This suggests that, in some individuals, the experience of climate change impacts blocked positive or negative beliefs about climate change, depending on the valence of the experience (SI table S3). However, polarization did not correlate with adaptation (SI table S5), and therefore, H1, which states that value polarization correlates with decision-making for climate change adaptation, was not corroborated.

Most forest professionals in the present study reported strong or moderately strong belief (as part of expectation) in climate change impacts on the forest and in having experienced the impacts of climate change (SI table S6). Hence, the variability in these variables was low (Q1-Q2 in table 1) (SI table S6). In previous studies in which decision-making in favor of adaptation of the forest to climate change correlated strongly with strength of belief in the local impacts of climate change and belief in having experienced its impacts, the variability was higher [11,23]. Hence, correlation between adaptation and strength of belief in climate change impacts on the forest was observed in the present study only in terms of adaptation being significantly more common among those who definitely believed in climate change impacts on forests (SI table S6). Correlation between adaptation and strength of belief in having experienced climate change was not observed, however (SI table S6). Hence, the empirical consequence 2a), i.e. the claim that strength of belief in the local impacts of climate change on the forest correlates with decision-making for climate change adaptation, was corroborated, whereas 2b), i.e. the claim that strength of belief in having experienced the impacts of climate change correlates with decision-making for climate change adaptation, was not. Our results indicate that strong belief in the impacts of climate change is a necessary, yet insufficient, requirement of decision-making for adaptation that may become stronger with communications strengthening the belief in having experienced climate change and its impacts (SI table S6).

While polarized positive and negative values of climate change impacts on the forest held true by respondents did not correlate with adaptation (SI table S5), net values of expected climate change impacts did (SI figures S1 and S2). Beliefs and expectations refer to different things. However, the difference in the observed correlations could be explained by psychological distance thinking. In such thinking, the overall beliefs in positive and negative impacts would refer to the "big picture" whereas the specific impacts in components of net values of expected climate change impacts would refer to more specific changes (cf. [24]). By definition, questions about overall impacts ask for generalizations and may trigger blocking on the individual level that results in the polarization of valuations on the population level. Questions about specific impacts, however, just like decision-making on adaptation, target knowledge about, in this case, climate change and its specific impacts on the forest. Hence, H3, which states that net values of expected climate change impacts correlate with decision-making for climate change adaptation, was corroborated.

Moreover, an alternative explanation of why polarized climate change impacts on the forest held true did not correlate with climate change adaptation can bee seen (SI table S5). It would indeed be rational for an agent to adapt irrespective of whether the impact held to be true had positive or negative value (see SI tables S4 and S10) (cf. [13]). Hence, the lack of correlation might be a result of there being too few response levels (Q1 in table 1) to reveal the non-linear relationship between adaptation and net values of expected climate change impacts on the forest (figure 3). If blocked beliefs were to have an effect on values where a (rational) decision would be affected by the resulting polarization (as happens when it comes to polarized values of trust in climate change scientists), they might indeed determine the success of climate change communications (cf. [9]). In particular, the blocking here would play a critical role if it were to occur among professional agents such as those in the present study.

Decisions in favor of climate change adaptation significantly correlated with the number of effective measures available, the level of self-reported authority to implement own ideas regarding climate change adaptation, and the net values of expected climate change impacts in a multivariate BART model. Furthermore, a systematic interaction between the covariates was revealed (figure 3). Hence, the empirical consequence 4a), which claims that the number of adaptation measures perceived to be effective correlates with decision-making for climate change adaptation, was corroborated. However, the correlation depended on net values of expected climate change impacts in a non-linear manner. Indeed, the results provide a more nuanced picture than that presented in previous studies (e.g. [10]). For moderately negative net values of expected climate change impacts, but not for positive net values, the utility expected resulted from a balance between net values of expected climate change impacts and the perceived availability of effective adaptation measures (figure 3).

In agreement with the requirements of rational decision-making [13], the expected utility of adaptation was low at net values of expected climate change impacts at and close to zero (figure 3). Forest professionals expecting close to zero, or moderately positive, net values of climate change impacts, and also reporting high authority to implement their own ideas regarding adaptation of forest management to climate change, expected more utility and thus were more likely to take measures to adapt to climate change (figure 3). The empirical consequence 4b), which claims that the perceived authority to implement own ideas regarding climate change adaptation correlates with decision-making for climate change adaptation, appears, therefore, to be corroborated. However, given that this variable correlated with adaptation at net values of expected climate change impacts on the forest at or close to zero, the correlation probably reflected a lack of relevant value objects in Q4-Q7 as well (SI table S1). Apparently, the forest professionals expected utility of adaptation other than that motivated by their expectations of impacts of climate change on the value objects included in this study. So, in this case, the empirical consequence 4.b) may not have been corroborated.

Where net values of expected climate change impacts were negative enough, adaptation was advocated without adaptation measures perceived to be highly effective (figure 3). However, this is not the case with tipping point behavior, a decision strategy first identified in the present study. None of the forest professionals with net values of expected impacts > 37 had advocated taking measures to adapt, and thus they too displayed tipping point behavior. Hence, the emipirical consequence 4c), which claims that tipping point behavior might occur for expected consequnces both uniformly better and worse in the relevant forest system than they are in the present system, was corroborated. Although experiential knowledge of climate change impacts on the forest was significantly more frequent among those expecting the most negative net values of climate change impacts, it did not correlate with adaptation. Moreover, it was lower among those expecting the most positive net values of climate change impacts (SI table S4). This indicates that experiential knowledge of the impacts of climate change on the forest was not the sole factor instigating tipping point behavior, see [12]. With the results of the empirical consequences combined, this means that H4, which states that perceived adaptive capacity correlates with decision-making for climate change adaptation, was at least partly corroborated.

Guidelines for adequate communications

Based on the communication needs (SI text S7) and decision strategies identified (figure 3), we developed the following guidelines for adequate communications (by communications we mean evidence-based communications, see [23]) with European forest professionals on adaptation to the impacts of climate change grouped by target audience (Segments as in figure

3). The target audiences are not mutually exclusive but reflect significant differences between countries:

Forest professionals with:

Weak local climate change beliefs

- Forest professionals with weak or uncertain belief in the local impacts of climate change on forests (cf. [11,24]), found most notably in Bulgaria and Finland, need communications on climate change *per se* and its impacts on the forest. Those with weak belief in having experienced the impacts of climate change need communications that strengthens that belief. Weak or uncertain belief in having experienced the impacts of climate change was commonest among forest professionals in Poland, Finland, the UK, Germany and Sweden (SI table S9).

Low net value of expected specific climate change impacts

- Forest professionals expecting no or very weak impacts of climate change on the forest (amounting to 7.2% of all respondents and represented in all countries but most notably in Poland, Germany and Romania [SI table S9]) (Segment III) need communications on climate change impacts on any forest value object.
- Forest professionals expecting positive and negative values of specific impacts of climate change on the forest that cancelled each other out (Segment III) need communications on the impacts of climate change on all objects for which the expected values are weak.
- Forest professionals expecting low strength of values of climate change impacts on the forest need communications on how climate change affects those value objects. Most forest professionals, but most notably in Slovakia, Romania, Italy and Portugal, expected low strength of values of climate change impacts for the value objects "return-", "pulp-", "timber-" and "energy production". An exception was the forest professionals from Finland and Sweden. There low strength of values were mainly for the value objects "rural livelihood development", "regulatory ecosystem services", "biodiversity", "recreation", "carbon storage", "non-timber production" and "hunting" (SI figure S3) (SI tables S4 and S9).

High absolute expected net value of specific climate change impacts

- Communications on negative specific impacts of climate change on forests are more likely to instigate forest adaptation of forest professionals across Europe than communications on positive specific climate change impacts (SI text S8).
- Forest professionals expecting moderately negative net values of climate change impacts on forests and seeing few effective adaptation measures (Segment II), found most notably in the UK, need communications on effective measures for climate change adaptation (SI figure S2) (SI table S12).
- Forest professionals expecting moderately negative net values of climate change impacts on forests and seeing several effective adaptation measures (Segment II), most notably found in Germany, need communications on the causal connections between climate change and negative impacts (SI figure S2). However, they do not need communications on even more effective measures as this would reduce the utility they expect from adaptation and thereby reduce their decision-making for climate change adaptation.

Tipping point behavior

- Communications for those who displayed tipping point behavior need to focus on whether or not relevant parts of the earth´s climate system have passed a tipping point (cf. [11,14]). Both negative and positive tipping point behavior was identified among the European forest professionals (Segments I and V). Negative tipping point behavior was most common in South-West Europe (Portugal), but also in Romania and Bulgaria, and positive tipping point behavior was most common in North-East and Northern Europe (Finland and Sweden) (SI table S11).

Conclusions

To be effective, communications on climate change must meet the needs of the receivers. Among European forest professionals significant patterns of correlations between climate change adaptation and beliefs and expectations are detectable. This suggests that the evidence-based guidelines for adequate communications we developed have the potential to help communicators meet the communication needs of European forest professionals on climate change forest adaptation. The new methodology presented in this study can be applied to a wide range of similar decision problems, such as citizens´decisions in response to environmental changes, including decisions involving tradeoffs among values.

We found that strong belief in local impacts of climate change was a prerequisite of decisions in favor of climate change adaptation. Moreover, adaptation to climate change correlated with net values of specific climate change expectations and generally, it increased with the absolute value of net expectations unless tipping point behavior occurred. Tipping point behavior was described in the present study for the first time. It was observed in South and South-West Europe as well as North and North-East Europe. Those exhibiting tipping point behavior believe that the earth (or relevant parts of it), has passed into a new system with uniformly worse or better consequences in the relevant forest system. Thus, for them, there is nothing to be gained from taking climate change adaptation action.

We found that the perceived capacity to adapt to climate change correlated with climate change adaptation but in a more complex way than previous studies have suggested. The finding that communications describing effective measures for climate change adaptation may encourage as well as inhibit decisions for adaptation depending on the net values of climate change expected by the receiver has important implications for climate change communication policy, and indeed for education curricula. We found that, unless they are balanced with communications on how climate change leads to negative impacts, communications focusing on effective adaptation measures could inhibit decision-making for adaptation if the receiver is aware of effective adaptation measures. Furthermore, those with weak expectations of impacts need communications on climate change and how it impacts on the forest before communications on measures can be effective.

We observed polarization in the positive and negative values of overall climate change impacts held true in half of the forest professional respondents. The polarization was triggered by a mechanism that has not been presented before which we call the "blocked beliefs" effect. Blocked beliefs correlated with experiences of climate change impacts but did not correlate with adaptation to climate change. Further investigation to establish whether the blocked beliefs effect triggers polarization of other values too is needed. The other values here include trust in climate change scientists, for which polarization might affect the strength of belief in climate change and thereby, potentially, profoundly impact climate change decisions for climate change action, especially among professionals.

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Acknowledgments: We are grateful to all respondents to the questionnaires for their valuable input. We thank Gail Atkinson for reviewing the English language of a draft questionnaire.

Funding: This paper is based upon work from COST Action FP1304 PROFOUND (Towards Robust Projections of European Forests under Climate Change), supported by the European Cooperation in Science and Technology (COST – www.cost.eu). The research was supported by The Swedish Energy Agency [grant number 45808-1] (to K.B.); The Swedish Research Council Formas [grant number 2019-00165] (to K.B. and J.P.) and [grant number 259-2008-1718] (to J.P.); The Swedish Foundation for Humanities and Social Sciences [grant number M14-0138:1] (to J.P.); Slovak Research and Development Agency, Projects No. APVV-18-0305 (J.M.); the grant 'EVA4.0', No. CZ.02.1.01/0.0/0.0/16_019/0000803 financed by OP RDE (K.M.); the German Federal Ministry of Education and Research (BMBF, grant no. 73 01LS1201A1) (to C.P.O.R.); the German Federal Office for Agriculture and FOOD (BLE, grant no. 2816ERA06S) (to C.P.O.R.).

Author contributions: K.B. and J.P. conceived the paper and wrote the first draft. K.B., L.G., J.P., A.B., I.D., J.H, E.J., M.L., J.M., K.M., M.P., M.P., F.R., G.V. and C.P.O.R. conducted the survey and K.B. carried out the analysis. All of the authors have reviewed the manuscript.

Competing interests: All authors declare no competing interests.

Data and materials availability: The data that support the findings of this study are available upon reasonable request from the authors.