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ORIGINAL PAPER

Perception of climate change-related forest dieback in mountain forests among the local population

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Abstract

Mountain forests provide multiple benefits but are threatened by climate change-induced forest dieback. Although many studies summarize perceptions of forest ecosystem services, relatively few deal with mountain forests. The local population's perception of forest dieback in mountain forests in relation to climate change has rarely been investigated so far. Their perspective is relevant as local people are often deeply attached to "their" forests, they actively use forest ecosystems and—as voters and taxpayers—they need to support the state's adaptation and funding measures. Therefore, this study investigates the climate change and forest dieback perception of local inhabitants in two mountain areas of Southern Germany (the German Alps and the Bavarian Forest) with a quantitative survey based on representative online samples ($n = 709$). Relying conceptually on van der Linden's (J Environ Psychol 41:112–124, 2015. https://doi.org/10.1016/j.jenvp.2014.11.012) climate change risk perception model, the results show that experiential processing, cognitive and socio-cultural factors are related to locals' forest dieback and climate change perception, while socio-demographics show no or few connections. Nearly two-thirds (64.7%) of the respondents perceive moderate to strong forest dieback, while more than half (55.0%) of the respondents already observe consequences of climate change. The perceptions of climate change and forest dieback are positively correlated with medium to high strength. This shows that forest dieback could be interpreted as an indicator of climate change, which is difficult to observe due to its long-term nature. We identify three groups of respondents regarding preferred forest adaptation strategies to climate change. In general, respondents support nature-based forest adaptation strategies over intense measures.

Keywords Forest dieback · Climate change · Mountain forests · Perception · Adaptation · Germany

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Introduction

Mountain forests and climate change-induced forest dieback

Mountain forests are very important for nature and humans, because they provide a wide range of ecosystem services. They not only regulate climate, e.g., due to carbon storage (Seidl et al. 2014), and provide a habitat for flora and fauna as well as a home and recreational space for humans (Richins 2016; Korner 2019), but they also protect against erosion, floods and avalanches (Schirpke et al. 2019). Moreover, mountain forests produce resources like timber, non-wood forest products (Langner et al. 2017) as well as drinking and irrigation water (Seidl et al. 2019). About 23% of the global lowland population is predicted to depend decisively on runoff contributions from mountains by the mid-twenty-first century (Viviroli et al. 2020).

However, forest ecosystems are strongly sensitive to climatic conditions, and they are thus distinctly affected by climate change (Turner et al. 2003; Seidl et al. 2011; Yousefpour and Hanewinkel 2016; Laurent et al. 2020). As the period from 2015 to 2019 is the warmest five-year period ever recorded (WMO 2019), it is unsurprising that climate change already affects mountain forests through a shift of growing seasons (IPCC 2020), vegetation boundaries (Hartl-Meier et al. 2014), and tree species composition (Köhl et al. 2017). Mountain forests also face an increasing risk of climate-induced dieback. Forest dieback—defined as tree mortality above usual levels—is documented on a global (Allen 2009; Senf et al. 2018; George et al. 2022) and local scale, as in the case of small mountainous areas in Central Europe (Bałazy et al. 2019).

For forests in the German federal state of Bavaria, forest experts list climate change as the most important influencing factor from a mid- and long-term perspective (Sacher and Mayer 2019). Especially in the Bavarian Forest and the German Alps in the southeast/south of Germany, the summers of 2018 and 2019 were characterized by heat and drought (Meinert et al. 2019). Forest fires were even reported in the usually humid German Alps (Süddeutsche Zeitung 2018). Vegetation and soils were directly affected by—for example—drought in the summer 2015 (StMELF 2017) and storm events in August 2017 (Klemmt et al. 2018). Additionally, bark beetle infestations affect large areas (Müller et al. 2008; Seidl et al. 2014; Thorn et al. 2017). Since ecosystem services of mountain forests are affected by climate change and resulting forest dieback, adaptation measures are essential. Adaptation—as defined by Moser (2010, p. 466)—involves "various responses by or interventions in a system, varying along a spectrum of relatively superficial adjustments to deep systemic changes, that allow a system to avert or minimize the negative consequences of a perturbation or take advantage of beneficial ones arising from it." Adaptation measures in forestry can reduce the vulnerability of forests and strengthen resilience and resistance for example by changing forest composition and structures with short- and long-term actions (Bolte et al. 2009; Keenan 2015; Yousefpour et al. 2017). Especially, forests at a high climate risk like spruce monocultures need to be adapted (Ammer 2009; Ruhm 2017). However, such adaptation measures are usually only realized if actors perceive these problems, are aware of their relevance and have the necessary resources (knowledge, power, networks, money) (Deuffic et al. 2020).

The role of public perception for climate change adaptation in a forest context

Choosing adequate climate change adaptation strategies and implementing the required measures accordingly requires incorporating public perceptions within a forest context. The literature includes the following reasons: First, Akerlof et al. (2013) note that public perceptions of local risks from global warming are increasingly important as communities face decisions about how to adapt most effectively to emerging changes. Therefore, Capstick et al. (2015) urge research attention to examine prospective trends and patterns in public perceptions across multiple regions. Second, climate change perceptions (e.g., Van der Linden 2015) have an influence on climate policies and are important to generate support for adaptation as well as mitigation initiatives (Lujala et al. 2015). In many cases, the ways in which societies, individuals and decision-makers respond to climate change relies on public perceptions about its causes, consequences and wider implications (Pidgeon and Fischhoff 2011; Lujala et al. 2015; Ruiz et al. 2020; Guo et al. 2021; Wang et al. 2022).

As forest dieback is one of the consequences of climate change posing a serious risk to forests as well as for the provision of ecosystem services (Allen 2009; Lindner et al. 2010), social science research about understanding the perceptions of climate change and related forest dieback in mountain areas is much needed. There are numerous reasons for decision-makers and researchers of all disciplines to take the population's perception of climate change and related forest dieback into account, such as developing effective and socially fair climate protection and adaptation measures (Grothmann et al. 2011; Sacher et al. 2017) or advancing the understanding of social-ecological climate change impacts (Morris et al. 2017). A high ratio of private forest owners with small-sized forest parcels in the Bavarian Forest and the German Alps makes it increasingly important to investigate climate change and forest dieback perceptions, because these private forest owners need to be involved in determining adaptation measures, and understanding expected impacts on local finances, landscape aesthetics, and identity. Moreover, residents are active users of forest ecosystem services and need to participate in the process of finding suitable adaptation measures because—for instance—climate change adaptation measures in their preferred forests might influence their recreational ecosystem services (Sacher et al. 2022). As residents are often deeply attached to "their" forests (e.g., Müller 2011), perceivable forest dieback caused by climate change could be interpreted by them as a concrete warning signal in the wake of the aggravating climate crisis (Deuffic et al. 2020; Brahic et al. 2022). In turn, this could increase people's support for the necessary, stricter climate protection measures as their direct environment is also affected by climate change impacts (Rudman et al. 2013). In addition, taxpayers must bear the costs of adaptation measures in case of public forests and support potential subsidies for private forest owners to incentivize them to adapt their forests.

However, while there are many studies summarizing public and/or stakeholders' perceptions of forest ecosystem services (e.g., European Commission 2009; Grilli et al. 2016; Ranacher et al. 2017), relatively few studies deal with mountain forests and ecosystem services (e.g., Rüdisser et al. 2019; Seidl et al. 2019). The public's forest dieback perception has been studied through pest outbreaks (McFarlane et al. 2012; Urquhart et al. 2017), on a limited number of species such as Norway Spruce (Chang et al. 2009) and Ash (Fellenor et al. 2019) and after extreme weather events (Urquhart et al. 2017). For instance, in their qualitative study Deuffic et al. (2020) focused on forest owners and not on the population as a whole. In addition, while researchers postulate climate change as a possible trigger for forest dieback, it is still unclear how the public perceives the link between both phenomena (Brahic et al. 2022). Thus, the perception of forest dieback in mountain forests among the local population is seldom investigated so far, reflecting a major research gap. Frick et al. (2018) note that information is urgently needed about how forests are perceived by residents and what preferences and demands they express. This is relevant for the following reasons: First and foremost, local residents are a crucial stakeholder group in forest ecosystem service management (Agbenyega et al. 2009) as forests constitute a "central part of almost all residents' everyday landscape" (Frick et al. 2018, p. 335) and as such are "highly valued by residents as part of their everyday living and recreational environment." (ibid.). Second, local residents' perceptions and attitudes about forests might differ significantly from those of forest owners, as Agbenyega et al. (2009) report regarding forest ecosystem services. These divergences could also lead to conflict. These questions are not only worth investigating to advise current policies but should also be monitored over time.

Of course, perception and awareness are not sufficient for adaptation measures. These notions need to be translated into concrete adaptation actions which also consider barriers to adaptation including lack of knowledge and information (Sousa-Silva et al. 2018; Hengst-Erhard 2019). Public support of adaptation measures is also decisive for making mountain forests resilient against climate change effects as studies have found evidence that public support is crucial for forest managers to implement adaptation measures. In general, public support is becoming increasingly significant for spatially relevant decisions and actions (Kemp et al. 2015; von Ruschkowski and Nienaber 2016; Peterson St-Laurent et al. 2018; Job et al. 2021).

Therefore, the aim of this contribution is to analyze local people's perception of mountain forest dieback in relation to climate change and their preferences regarding adaptation strategies. We use a quantitative online survey based on a representative sample examining local residents' forest dieback and climate change perceptions for the example of two mountain forest areas in Southern Germany, the German Alps and the Bavarian Forest. The two regions have similar proportions of forest areas, whereas the German Alps reach higher altitudes (2962 m asl at maximum), and the Bavarian Forest lower altitudes (1456 m asl at maximum). Both areas are affected by climate change-induced forest dieback.

We address the following research questions: (1) Do respondents perceive changes in the forests, e.g., forest dieback or other forest damages? (2) Are these changes perceived to be related to climate change, and how do respondents perceive climate change in general? (3) Which factors have an impact on the perception of forest dieback and climate change? (4) Which silvicultural adaptation strategies are favored by the public?

We underpin our results by using the theoretical model of van der Linden (2015), which was originally used in a climate risk perception context and is now tested for the first time in a forest dieback context while combining it with separate perceptional processes. Further, this model should serve to explain the complex perceptional processes behind the public's preference for silvicultural adaptation measures, which has not been tested by other researchers so far. In this way, we try to close the identified research gap about forest dieback and climate change perceptions of local inhabitants in mountain areas in contrast to the much more prominently covered forest managers and owners.

Climate change risk perception model

The climate change risk perception model (CCRPM) of van der Linden (2015) serves as the theoretical foundation of this study to better understand the social-psychological determinants of risk perception in a forestry context.

The CCPRM (see Fig. 2 in section "Perception of forests and forest dieback") includes psychological influencing factors on the risk perception of climate change. The model describes four key dimensions: (1) cognitive, (2) experiential processing, (3) socio-cultural and (4) socio-demographic factors.

1. Cognitive factors refer to the subjective estimation of the probability that global warming is likely to happen and the severity of the associated consequences. Knowledge about climate change is generally seen as a cognitive aspect of risk judgments (Sundblad et al. 2007). In addition, analyses of public perceptions have indicated that climate change is perceived as being psychologically distant on temporal, social, geographical scales, and uncertainty dimensions (Spence et al. 2012). However, cognitive knowledge plays only one part in explaining perceptions and behavior, while other factors such as heuristics, emotions, social and cultural norms and context conditions in which knowledge arises or is situated are equally relevant in many cases (Helgeson et al. 2012).

2. Experiential processing could be described by emotions and affect as well as personal experiences. Emotional reactions to climate change have been recognized as playing a key role in public risk perception (Taylor et al. 2014). The media and news reporting has an immediate influence on climate change perception (Keller 2011). However, emotional reactions to climate change risks are likely to be conflicted and muted because climate change can be seen as being beyond the control of individuals, communities, and—quite possibly—science and technology. Strong negative emotions can have a counterproductive consequence on risk protection behavior because fear and anxiety lead to avoidant behaviors and defensive denial (Witte and Allen 2000), besides the fact that climate change is not perceptible and concern about climate change is mostly experience-driven (Grothmann and Patt 2005). The personal experience with natural hazards and personal damage caused by climate-related events is seen as a main factor explaining people's climate change perception (Lujala et al. 2015; Frondel et al. 2017)—that means, direct (negative) experiences can increase risk perceptions.
3. Socio-cultural influences refer to the role of competing social and cultural structures in shaping individual risk perception (Jackson et al. 2006). According to the conceptual typology of risk culture and its "grid-group" system (van der Linden 2015), the relative position of the cultural types is determined by the extent to which individuals feel bounded by feelings of belonging and solidarity (group) and the amount of control and structure that maintain social roles (grid). However, while a few studies have found significant relationships between cultural worldviews and risk perception of climate change (Akerlof et al. 2013; Smith and Leiserowitz 2012), others have shown a low explanatory power (Oltedal et al. 2004). In addition, the political ideology plays a role within perception process (Leiserowitz 2006; Smith and Leiserowitz 2012). Conservatives have been found to be less concerned about climate change compared to liberals (Goldberg et al. 2020).
4. Socio-demographics: Some studies reveal that gender influences climate change risk perception (Menny et al. 2011; Poortinga et al. 2019). Males tend to have lower risk perceptions than females (Brody et al. 2007; Sundblad et al. 2007; Fulda and Hövermann 2020). Moreover, Echvarren et al. (2019) report that people with higher education levels have stronger concerns about climate change in European countries that are more vulnerable to floods and droughts. Furthermore, Blennow et al. (2016) demonstrate that the risk perception in terms of the strength of belief in the local effects of climate change is higher for Swedish and German forest owners with a university education compared with those without. While gender and education are able to shape risk perception, it is less clear if other factors like income and age influence climate change risk perception (Brody et al. 2007; Sundblad et al. 2007; Milfont 2012; Poortinga et al. 2019).

While Soucy et al. (2021) found the CCRPM model to be valid in a forestry context, we extended the model by a forest dieback risk perception variable to better adapt the model to the forest dieback and climate change discourse and the regional context. Climate change is a slow-onset hazard which is rather perceivable by its impacts like forest damages than by itself. However, lay people (Brahic et al. 2022) or forest stakeholders (Deuffic et al. 2020) may not always relate forest dieback to climate change or are uncertain about the causes of forest damages. Therefore, it may be insufficient to only test a climate change perception variable in this specific context. With the integration of a second perceptional variable, we see the potential to (1) better describe the determinants of both perceptional variables as well as to identify differences and to (2) test whether respondents perceive a link between climate change and forest dieback perception.

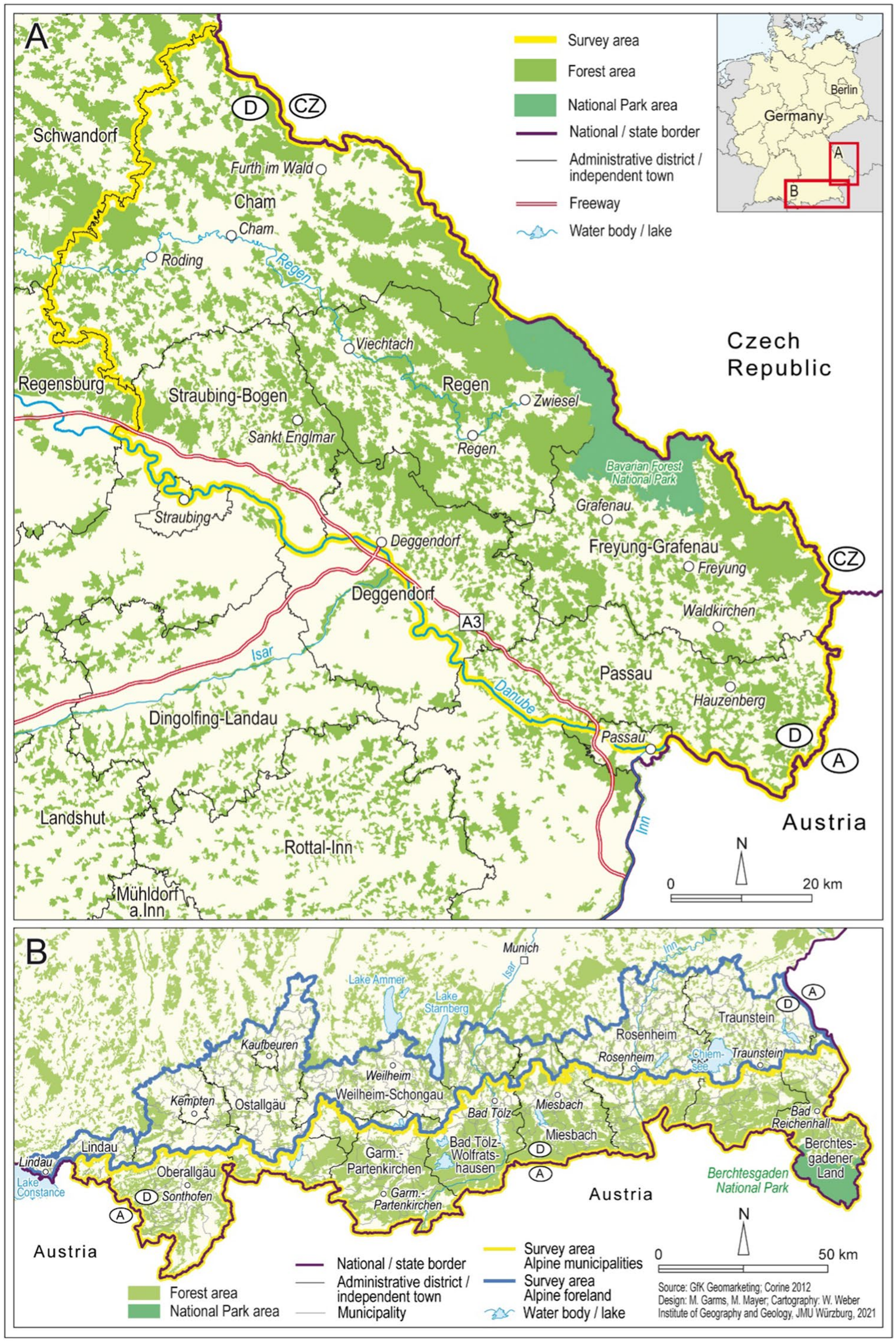
Material and methods

Study areas

Both study areas—the Bavarian Forest and the German Alps—are located in southern Germany (Fig. 1a, b). The German Alps are a relatively small part of the European Alps (3.5%) located along the southern German border to Austria with a West-to-East extension of 250 km and a north-to-south extension of only 20–35 km (Mayer and Job 2014; Fickert 2018). Nevertheless, with its highest mountain ranges of the Wetterstein (Zugspitze, 2962 m asl), the Allgäuer Alps, the Karwendelgebirge as well as the Berchtesgaden Alps, it reaches high alpine areas. The study area in the German Alps includes communities in the German Alps as well as in their flat foreland in the north. The Bavarian Forest is a densely forested low-mountain range (Großer Arber, 1456 m asl) located along the border between Germany and the Czech Republic in the southeast of Germany (Mayer 2013). This second study area is about half the size of the study area in the German Alps and their foreland and also includes some of the population centers at the river Danube (Table 1).

The Bavarian Forest is located in a transition region from the continental to the oceanic climatic zone with low temperatures and high precipitation at high altitudes (Burger 2003). The annual precipitation increases from West to East, with 650 mm at a minimum and 1850 mm at a maximum

Fig. 1 **a**, **b** Maps of the survey areas



(Bässler 2008). The mean temperature is between 4 °C at high altitudes and 6 °C at low altitudes (Walentowski and Kopp 2006). The climate in the German Alps is characterized by low temperatures in winter and precipitation all year round within the cool-temperate zone (Bätzing 2015; Fickert 2018). The mean temperature is between 1 °C at high altitudes and 8.5 °C at low altitudes. The annual precipitation varies between 900 and 2500 mm (StMELF 2016).

The share of forest area reaches 47% in the Bavarian Forest (Destatis 2019) and 50% in the German Alps (StMELF 2016). The main tree species are spruce, beech and fir, whereby this co-occurrence is typical of mountain forests due to climatic conditions (LWF 2001; Ellenberg and Leuschner 2010). However, both mountain forest areas have a higher than natural share of spruce (at least 50%) due to anthropogenic influences. For instance, spruce was

Table 1 Comparison of the study areas

	Bavarian Forest	German Alps
Area (in km^2)	5400	11,200
Population (as for 2018)	506,518	1,274,879
Population density	93.8 p/km^2	113.8 p/km^2
Forest area (in %)	47	50
Mountain formation	Low mountain range	High mountain range
Absolute altitude (m asl)	1456	2962
Max. altitudinal belt	Subalpin	Nival
Vegetation	Deciduous and coniferous tree species, with high amount of spruce due to anthropogenic impact	
Measures against forest damages	Adaptation und mitigation by the climate concept of the Bavarian forest administration	

Source: own draft based on Binder and Höllerl (2011), StMELF (2017), Klemmt et al. (2018), Destatis (2019)

favored by forest management in the past due to its economic potential and relatively high growth rates. Moreover, climate change affects the growing conditions in both study areas through higher average temperatures and less average annual precipitation (Kölling et al. 2007; Hartl-Meier et al. 2014).

Both study areas are affected by climate-induced forest dieback, which is associated with a change in small-scale climatic conditions, an increase in the frequency of extreme events, and a shift in phenological phases (e.g., Kölling et al. 2007; Müller et al. 2008; StMUV 2015; StMELF 2017; Klemmt et al. 2018).

Regarding the socioeconomic structure both survey areas are regarded as rural areas according to the Federal Institute on Building, Urban Affairs and Spatial Development (BBSR 2018), with the exception of the district of Rosenheim in the German Alps. The districts of the Bavarian Forest survey area are even characterized as sparsely settled districts (except for Passau) as are five of the districts in the German Alps. This corresponds to the well below average population densities (Table 1) compared to the German average of 237 inhabitants per km^2 in 2018 (Statista 2023). The population development in the German Alps is overall positive (with exceptions of more peripheral municipalities), driven by attractive living conditions as well as commuting to the agglomeration of Munich and other perialpine cities. The economic structure is typical for post-modern service economies but with a still strong manufacturing sector and local tourism hotspots (Mayer and Job 2014, LfSta 2023a). As for the GDP per inhabitants the districts of the German Alps have a mean rank of 55.7 among the 96 Bavarian districts (own calculations based on LfStA 2023b), underlining the rural character. The demographic structure of the Bavarian Forest survey area is less positive, with higher shares of municipalities losing inhabitants, especially in the Inner Bavarian Forest (districts Freyung-Grafenau and Regen). The districts of the Bavarian Forest survey area reach a mean rank of 64.2 among the 96 Bavarian districts in terms of GDP/capita (own calculations based on LfStA 2023b) which indicates an overall less dynamic economic development and a less affluent population. Nevertheless, the economic structure of the Bavarian Forest has improved considerably since the Second World War, turning the former "poorhouse of the nation" into attractive rural areas with a broad mixture of industries (manufacturing, tourism) and commuting possibilities to employers like BMW. Due to its economic history, forestry, wood processing and wood-based industries still have a strong position in the mindset of the local population despite a much reduced economic relevance in the last decades (Mayer 2013; Garms 2021).

Survey design and measures of the model

To perform a quantitative analysis of residents' forest dieback and climate change perception, we used a standardized questionnaire, which included questions about the general relation to mountain forests, environmental worldviews in general, perceptions and attitudes regarding climate change and forest damages in the mountain forests and questions about the preference of adaptation measures as well as sociodemographic characteristics. However, we focused on the analysis of perceptions. The questionnaire was ordered thematically. First, respondents were asked about forest-related topics, e.g., preferred activities and valued characteristics of a forest. Second, we asked them to name potential risks to forests (open question format) and, next, to rank potential threats to forests (among them climate change). In the questionnaire, respondents were not informed about climate change before. Thus, these questions assess the respondents' problem awareness as well as if they identify the potential link between forest threats and climate change. Third, questions about climate change and adaptation to forest dieback and climate change were asked. In addition to single- and multiple-choice questions, five-point Likert-type scales and ranking tasks were used.

Table 2 Measures and survey instruments for the CCRPM model

Factors of the CCRPM model	Literature	Questions/propositions in the survey instrument	Measurement method
Cognitive factors	For example, Blennow et al. (2016), Milfont (2012)	Please judge your own knowledge on the topic "forests" Please judge your own knowledge on the topic "climate change"	5-point Likert-type scale
Experiential Processing	For example, Soucy et al. (2021)	Were you personally affected by climate change?	Categorial
Socio-cultural	Farjon et al. (2016), Sacher (2020)	Environmental worldviews: Vulnerable nature areas should be closed to leisure and recreational activities We should use nature in such a way that we get the most economic value from it Too much emphasis has been placed on nature conservation Hunting is cruel and inhumane to animals It is natural that wild animals sometimes starve to death or are injured by other animals and we should accept that Trees may be felled if need be to increase the diversity of species in a forest Deadwood attitude[a]: Deadwood is a source of danger for forest visitors Deadwood is important for the survival of rare species and leads to more natural forests	5-point Likert-type scale
Socio-demographic factors	For example, Poortinga et al. (2019)	Age (How old are you?)	Metric
		Education (What is the highest level of school education you have completed?)	Categorial
		Gender	Categorial
		Income class (Which category applies to your monthly net household income?)	Ordinal
		Profession (What is your professional situation?)	Categorical
		Relation to forestry (Is your professional situation related to forestry?)	Categorial

Source: Own draft

[a]Extract, for an original list with 23 items, see Sacher (2020)

Table 2 describes measures for each construct of the CCRP model. The cognitive factor is measured by the respondents' self-assessed degree of knowledge concerning climate change and forest dieback. The variable experiential processing is identified by asking the respondents if they were already personally affected by climate change. The socio-cultural factor is summarized by environmental worldviews and the respondents' deadwood attitude. The scale of Farjon et al. (2016) takes into account the normative dimension or values of nature and was originally used to identify the European citizens' support for nature policies. The authors distinguish three dominant environmental worldviews (ecocentric, anthropocentric and holistic) which are based on a set of six propositions (see Table 2). For instance, respondents grouped into the ecocentric worldview appreciate the intrinsic value of nature and respondents grouped into the anthropocentric worldview agree with a utilitarian value of nature. Moreover, we integrated a deadwood attitude variable in our model as forest dieback is immediately combined with the occurrence of unusual high amounts of deadwood and past research indicate that deadwood attitude has an impact on the respondents' forest perception (see, e.g., Sacher 2020; Sacher et al. 2022). The socio-demographic factor is described by the variables age, education, gender, income class, profession and professional relation to forestry.

Data collection and analysis

A renowned market research company representatively recruited the respondents based on pre-set quotas (gender, age groups) from an online panel. The survey was presented online, and the pre-test was implemented in August 2018 with 54 participants. The full survey was launched between

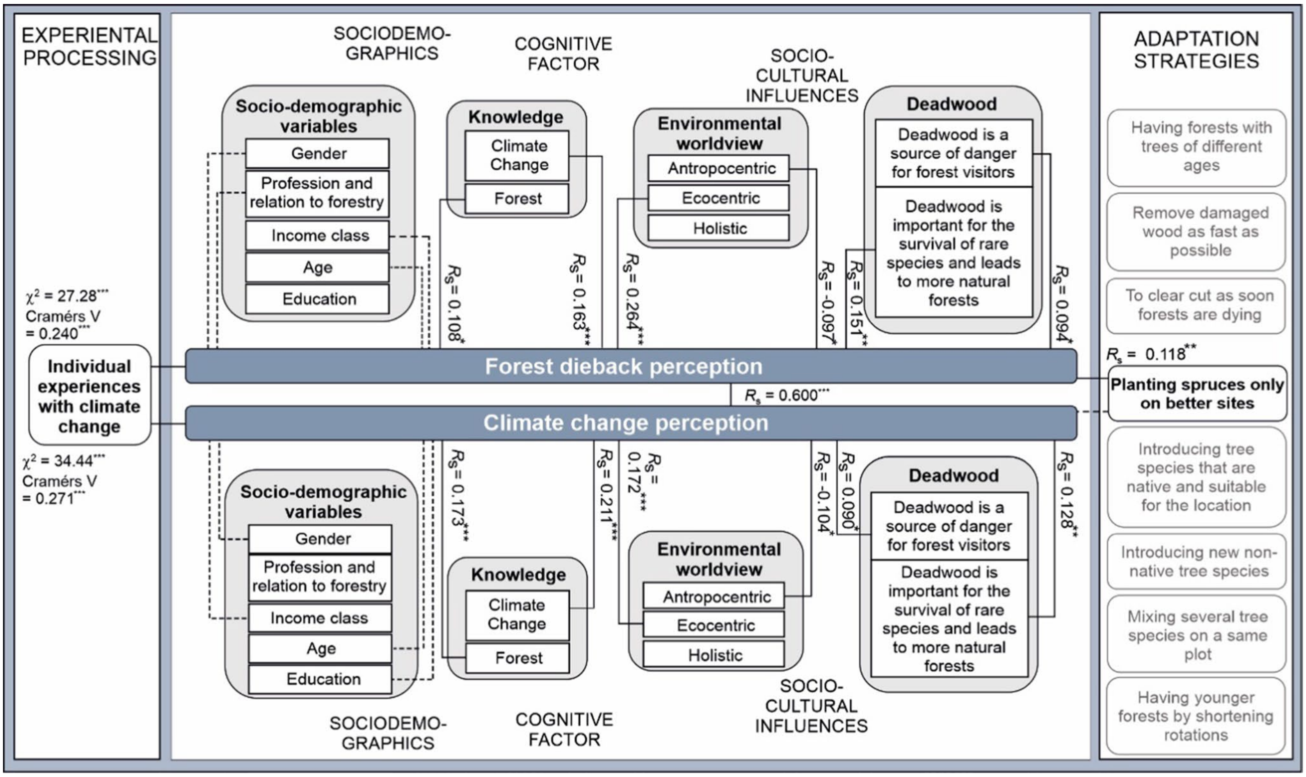


Fig. 2 Correlations between perceptions of forest dieback and climate change. *Notes*: Consistent lines show significant correlations; dashed lines mark nonsignificant results, likewise gray-shaded adaptation strategies; variables without lines do not meet the requirements for checking the correlations. *Source*: Own draft based on van der Linden (2015)

August and September 2018 and included 709 participants, comprising 305 residents of the study area Bavarian Forest and 404 residents of the study area German Alps. The latter can be differentiated again into 303 respondents of the Alpine municipalities and 101 respondents of the Alpine foreland. The data were weighted based on socio-demographic characteristics (gender, age and administrative district) and can be therefore regarded as representative for the survey areas. Due to very few statistically significant differences in the answers given in each study area, in the following both samples are analyzed together and existing differences between the regions are highlighted.

We analyzed the dataset with IBM SPSS Statistics 22, with the chosen level of significance of $\alpha = 0.05$. In particular, comparisons of means (*t* test, ANOVA) between groups of respondents and tests of statistical relationships (chi-square test, Spearman's correlation analysis) were used. In some cases, the respondents were asked to classify the four most relevant responses according to their personal assessment, from rank one as the most important to rank four as the least important. For further statistical analyses, these questions have been recoded (0 = not chosen, 4 = ranked 1, i.e., not important at all to 4 most important).

In addition, the environmental worldview was analyzed based on Farjon et al. (2016). A factor analysis (Table 5 in Appendix) resulted in an extraction of three components from six items ($\lambda_1 = 1.45$; $\lambda_2 = 1.34$; $\lambda_3 = 1.09$) that explain 64.7% of the total variance. They imply an anthropocentric, holistic and ecocentric environmental worldview.

To evaluate the theoretical model, aggregated variables were calculated. The new variable *perception of forest dieback* is a construct of the questions concerning threats to forests and forest dieback impacts on the forests. The scale ranges from one reflecting "not at all impacted" to five denoting "extremely impacted." A reliability check shows the internal consistency of the questions with a Cronbach's alpha score of 0.67. The variable *climate change perception* was generated based on the questions concerning climate change consequences in the study area, current climate change impact on the forests and future impact of climate change on the forests. The scale ranges from one marking "not at all" to five representing "extremely." A Cronbach's alpha score of 0.79 illustrates the internal consistency of the questions. Spearman correlations (respectively, Cramer's *V* tests for nominal-scaled variables) were used to analyze the relations between the components of the CCRP model, adaptations strategies and potential socio-demographic influences (see Fig. 2).

Finally, a cluster analysis was conducted to aggregate preferred mountain forest adaptation strategies. Therefore, the Ward method was applied on eight adaptation strategies. As a last step, we related the resulting clusters to climate change and forest dieback perception as well as to the environmental worldview clusters and socio-demographics.

Results

Socio-demographic characteristics of the respondents

On average, the respondents are 51 years old. The weighted sample contains slightly more women than men (Table 6 in Appendix). Most respondents reached a secondary educational level (43.2%) had a professional qualification or a university degree (70.9%) and a monthly net household income of between 2000€ and 2499€ (16.0%). The largest group of respondents are retirees or pensioners (29.5%), followed by other officials, and employees (25.8%). Most respondents have no professional relation to forestry (96.5%) and do not own forests (91.9%), while 17.5% are members of an association (e.g., nature protection, hunting/fishing, forest owners).

Perception of forests and forest dieback

Respondents of both study areas reported that they had visited forests at least once a month over the past 12 months. On average, they were more frequently in the forests than once a month. Regarding the question of how informed the respondents feel about forests, 35.9% answered that they feel well to very well informed (Table 3). The most frequent answer (50.9%) was to feel moderately informed. Forest owners assess their knowledge level as significantly higher (mean 3.86; SD 0.59) than non-forest owners (mean 3.19; SD 0.75; *t*-value 7.37***).

The most popular characteristic of the forests in both study areas is mixed forests (top-two box values[1] 58.0%; mean 2.5, scale from 0 = not chosen to 4 = most popular; SD 1.5), followed by paths (40.5%; mean 1.9; SD 1.5) and richness of flora and fauna (41.5%; mean 1.9; SD 1.5). The least popular characteristic is deadwood (86.8% not chosen; mean 0.2; SD 0.7). Regarding the functions of the forests, the respondents had to choose four out of nine categories and sort them based on their subjectively perceived relevance (Table 3). The most frequent category ranked first is preserving the air and soil quality and water resources (50.2%; mean 2.3; SD 1.5), while the least frequent function is producing wood (80.6% not chosen; mean 0.4; SD 0.8). In the Bavarian Forest, being a cultural heritage (*t*-value = 3.3***), providing beautiful landscapes (*t*-value = 3.7***), producing wood (*t*-value = 2.1*) and being a recreational area (*t*-value = 4.7***) are more relevant. In the German Alps, the functions of preserving the air and soil quality and water resources (*t*-value = − 2.6**), mitigating global warming (*t*-value = − 3.0**) and protecting people from natural hazards (*t*-value = − 6.1***) are more relevant.

In an open question, we asked respondents about the three main risks for forests without having referred to climate change in any sentence of the questionnaire before. Among the multiple answers ($n = 1201$) 27.1% of the answers referred directly to climate change and its abiotical impacts (e.g., drought/heat, more storms, extreme weather events, forest fires) while 16.5% referred to bark beetle impacts (a biotic impact which could be triggered by climate change). However, a significant share of respondents (11.3%) also sees tourism (e.g., deforestation for ski slopes) and unsuitable behavior of recreationists as main forest risks—much more than, for instance, environmental/air pollution (9.4%) or monocultures (4.2%).

Asked with closed questions, the large majority of the respondents perceive abiotic (top-two box values 77.4%; mean 4.0; SD 0.9) as well as biotic changes (73.8%; mean 4.0; SD 0.9) and increasing forest dieback (60.2%; mean 3.6; SD 1.0) in the study areas since 1980 (Table 3). More than half of the respondents in both study areas think that the forests are endangered (54.1%; mean 3.5) and currently affected by forest damages (57.2%; mean 3.6). Pests, diseases and invasive species are mentioned as the main risks to the forests (41.2%; mean 1.92; SD 1.5). Climate change was listed as the second most important risk (37.4%; mean 1.76; SD 1.6). The most strongly manifested impacts of forest dieback at present are a disappearance of protected species (63.2%; mean 3.8; SD 1.1) and an increasing volume of deadwood (65.8%; mean 3.8; SD 0.9). A recession of forest economic activities due to increased forest dieback holds the least concern for the respondents (38.4%; mean 3.2; SD 1.1). The new aggregated variable *perception of forest dieback* shows that nearly two-thirds of the respondents perceive moderate to strong forest dieback (top-two box values 64.7%; mean 3.73; SD 0.76), while only three respondents (0.5%) do not perceive forest damages at all. There is no significant difference in perception of forest dieback between the Bavarian Forest (mean 3.72; SD 0.80) and the German Alps (mean 3.74; SD 0.75; *t*-value = − 0.27). Forest owners perceive forest dieback more strongly (mean 3.89; SD 0.8) than non-forest owners (mean 3.72; SD 0.8; *t*-value = 1.44). However, this

[1] Top-two box values are a way of summarizing the positive responses from a Likert scale-type survey question. It combines the highest two responses of the scale to create a single number (SurveyMonkey 2023).

Table 3 Perception of forests and forest dieback (in percentages)

		Very good (5)	Good (4)	Medium (3)	Bad (2)	Very bad (1)	*Mean*	*SD*
Please judge your own knowledge on the topic "forests".		3.22	32.72	**50.93**	11.57	1.56	3.24	0.76
		Most popular (4)	**(3)**	**(2)**	**Least popular (1)**	**Not chosen (0)**	***Mean***	***SD***
Which of the following characteristics of the forests in the study area do you like the most? (Rank 4)	Mixed forests	33.23	24.81	15.02	8.83	18.11	2.46	1.48
	Paths	18.51	22.00	19.58	12.43	27.49	1.92	1.48
	Fauna and flora richness	23.90	17.58	15.35	15.29	27.88	1.94	1.55
	Open spaces	8.83	12.77	19.22	23.08	36.10	1.35	1.32
	Broadleaves stands	6.80	8.19	7.20	9.03	68.78	0.75	1.28
	Understory with shrubs and small trees	0.72	3.27	9.26	9.63	77.13	0.41	0.84
	Recreative area	2.73	4.47	6.43	6.89	79.49	0.44	0.99
	Conifers stands	4.85	4.50	4.21	6.21	80.23	0.48	1.09
	Deadwood	0.36	2.37	3.39	7.05	86.81	0.22	0.66
According to you, what are the most important key functions of the forests of the study area? (Rank 4)	Preserving the air and soil quality and water resources	28.76	21.38	16.92	11.53	21.42	2.25	1.51
	Contributing to health and quality of life	16.51	18.87	16.32	16.81	31.50	1.72	1.48
	Being an area for conservation of animals and plants diversity	15.29	18.05	18.37	16.06	32.22	1.68	1.46
	Protecting people from natural hazards	14.91	14.80	14.21	12.39	43.69	1.45	1.52
	Being a recreational area	6.99	6.55	9.70	10.71	66.04	0.78	1.27
	Mitigating global warming	7.56	8.23	5.76	6.63	71.82	0.73	1.31
	Providing a beautiful landscape	4.96	5.59	7.28	7.84	74.33	0.59	1.15
	Being a cultural heritage	3.16	4.39	4.98	9.12	78.35	0.45	1.00
	Producing wood	1.86	2.14	6.45	8.91	80.64	0.36	0.84
According to you, which are the four main threats to the forests of the study area? (Rank 4)	Pests, diseases, invasive species	21.63	19.57	14.80	17.13	26.88	1.92	1.52
	Climate change	24.17	13.22	13.72	12.49	36.39	1.76	1.62
	Storm	6.96	16.02	12.33	9.03	55.66	1.10	1.39
	Drought	7.80	13.09	12.35	9.21	57.55	1.04	1.39
	Over-harvesting of wood products	11.05	8.78	8.04	9.12	63.02	0.96	1.44
	Over frequentation by public	9.07	8.57	9.43	10.75	62.18	0.92	1.37
	Fire	9.42	5.68	5.78	4.39	74.73	0.71	1.34
	Forest damages	3.58	4.09	4.17	8.60	79.56	0.44	1.00
	Lack of forest management	1.54	1.98	6.81	7.40	82.26	0.33	0.81
	Over-harvesting of non-wood products	1.45	3.98	5.55	3.82	85.20	0.33	0.86
	Snowfall, snow break	1.11	2.88	5.41	3.89	86.71	0.28	0.79
	Deer browsing	1.22	1.85	1.11	2.86	92.96	0.16	0.64
		Strongly (5)	**(4)**	**Partly (3)**	**(2)**	**Not at all (1)**	***Mean***	***SD***
To what extent do you agree or disagree with each of the following statements about the forest specific changes in the study area since 1980 (or since you can judge)?	Abiotic forest damages (e.g. wind throw, snow damage, forest fires) increase.	33.39	44.02	16.35	5.59	0.65	4.04	0.88
	Biotic forest damages (e.g. bark beetle and pest outbreak) increase.	36.10	37.69	19.77	5.92	0.53	4.03	0.92
	Tree mortality increases (forest dieback).	21.80	38.41	23.22	15.53	1.04	3.64	1.02
	The number of pure spruce forests (monoculture) decreases.	11.89	42.51	30.42	13.26	1.91	3.49	0.93
	The share of broadleaved trees increases.	8.21	36.73	31.08	21.73	2.25	3.27	0.97
	Fauna and flora richness increases.	3.18	17.21	34.24	35.68	9.71	2.68	0.97
Do you think the forests of the study area are threatened?		9.98	44.14	35.76	9.48	0.63	3.53	0.82
To what extent do you think that the forests of the study area are impacted by forest dieback?		10.43	46.83	34.37	7.87	0.50	3.59	0.80
Which impacts of forest dieback are currently seen in the study area in your opinion?	Disappearance of protected species	32.70	30.46	20.65	13.29	2.88	3.77	1.13
	Increasing volume of deadwood	20.37	45.36	24.00	9.11	1.16	3.75	0.92
	Landscape degradation	19.91	41.22	25.10	11.66	2.12	3.65	0.99
	Decrease of micro fauna	24.80	34.53	24.11	12.80	3.76	3.64	1.10
	Loss of non-timber products	24.38	29.09	24.06	18.72	3.75	3.52	1.16
	Change in understory vegetation	15.89	33.56	35.16	13.36	2.04	3.48	0.98
	Recession in forestry sector	13.72	24.75	33.66	21.58	6.29	3.18	1.11
Perception of forest dieback (aggregated)		13.67	51.00	30.71	4.16	0.46	3.73	0.76
	Yes, I go less into the forest.	**Yes, I changed the place for my forest walks.**	**Yes, I changed my practices in another way.**		**No, forest dieback doesn't influence my leisure practices.**			
Does forest dieback have any influence on your leisure time practices in the study area?	16.26	11.46	3.49		64.65			

Gray tones indicate the frequency of answers: dark gray most frequent answer, gray 2nd frequent answer, light gray 3rd frequent answer

Table 4 Perception of climate change (in percentages)

What is your opinion on climate change?	I think climate change is real and is partly caused by natural processes and partly caused by human activities.	I think climate change is real and is only caused by human activities.	I think climate change is real and is based on a natural variation in earth's temperature.	I don't know if climate change is real or not.	I don't think climate is changing.	I have no categorical opinion.		
	54.56	30.16	9.00	2.14	1.90	2.24		
		Very good (5)	Good (4)	Medium (3)	Bad (2)	Very bad (1)	*Mean*	*SD*
Please judge your own knowledge on the topic "climate change".		5.99	34.60	**49.12**	9.71	0.58	3.36	0.76
		Yes	No					
Were you personally affected by climate change?		28.69	**71.31**					
		Strongly (5)	(4)	Partly (3)	(2)	Not at all (1)	*Mean*	*SD*
Do you think there are already consequences of climate change in the study area?		6.54	**45.45**	34.73	12.55	0.72	3.45	0.82
To what extent is the study area already impacted by climate change?	Drier summers	**43.42**	39.00	13.43	3.52	0.62	4.21	0.85
	Warmer winters	32.10	**43.95**	16.25	6.96	0.74	4.00	0.91
	More storms	33.44	**38.12**	19.89	7.55	0.99	3.95	0.96
	More flood	23.96	**35.36**	21.15	14.70	4.82	3.59	1.14
	More fire	18.70	**31.45**	21.30	21.66	6.90	3.33	1.20
Do you think that the forests of the study area are currently impacted by climate change?		3.41	**42.63**	36.45	16.42	1.09	3.31	0.82
Which impacts of climate change do you currently recognize in the forests of the study area?	Increase in forest damages (e.g. insects, pest outbreaks)	29.32	40.27	19.81	9.44	1.15	3.87	0.98
	Increase in tree mortality	17.75	39.32	25.23	15.71	2.00	3.55	1.02
	Forest landscape degradation (e.g. due to soil erosion)	16.12	40.84	25.52	14.43	3.10	3.52	1.02
	Change in tree species composition	11.12	35.20	34.29	16.61	2.78	3.35	0.98
	Change in flora and fauna diversity in the forest	11.21	30.40	37.31	17.58	3.51	3.28	1.00
	Change in soil fertility	11.47	29.63	32.47	22.10	4.33	3.22	1.05
	Decrease in tree growth	8.90	27.94	33.92	24.14	5.09	3.11	1.03
	Increase in tree growth	2.96	8.46	28.64	52.30	7.65	2.47	0.87
Do you think the forests of the study area will be impacted by climate change in the future (from now to 2050)?		24.03	61.64	11.00	3.01	0.31	4.06	0.70
Perception of climate change (aggregated)		5.88	54.95	32.51	6.47	0.19	3.60	0.71
		…has already happened for the last 20 years.	…happens today.	…will only happen in the future.				
Do you think forest dieback in the study area is an event that…		72.34	23.21	4.46				

Gray tones indicate the frequency of answers: dark gray most frequent answer, gray 2nd frequent answer, light gray 3rd frequent answer

tendency is not significant, which might be due to the small sample size of forest owners ($n = 48$).

The upper part of Fig. 2 shows the relationship between forest dieback perception and the dimensions of van der Linden's (2015) CCPRM model. Regarding the cognitive dimension, the higher that respondents estimate their state of knowledge about both climate change and forests, the more they perceive forest dieback. Experiential processing plays an important role: the stronger participants themselves state being affected by climate change—i.e., having already individually experienced climate change—the more they perceive forest dieback. In terms of the socio-cultural dimension, the more ecocentric the respondents' environmental worldview, the more they perceive forest damage, while the more that participants agree with anthropocentrism, the less they perceive forest damage. If the respondents see deadwood as a source of danger for forest visitors and as ecologically important, they perceive forest dieback more strongly. The factors of the socio-demographic dimension are not significantly correlated with forest dieback perception. Finally, an approval of the adaptation strategy to plant spruce only on suitable stands positively correlates with the forest dieback perception.

Perception of climate change

The overwhelming majority of respondents (93.8%) think that climate change is real (Table 4). The level of information about climate change is rather high in the sample, as 40.6% answered that they feel rather well to very well informed. The most frequent answer (49.1%) was to feel moderately informed. However, by contrast, only a minority of the respondents (28.7%) have already been personally affected by climate change. More than 90% of this subgroup mentioned weather extremes as an example, while about half of the respondents mentioned heat and drought. Regarding personal experience with climate change, forest owners state that they were affected significantly more often by climate change than non-forest owners (χ^2 ($N = 590$) = 8.790**; Phi = 0.136**).

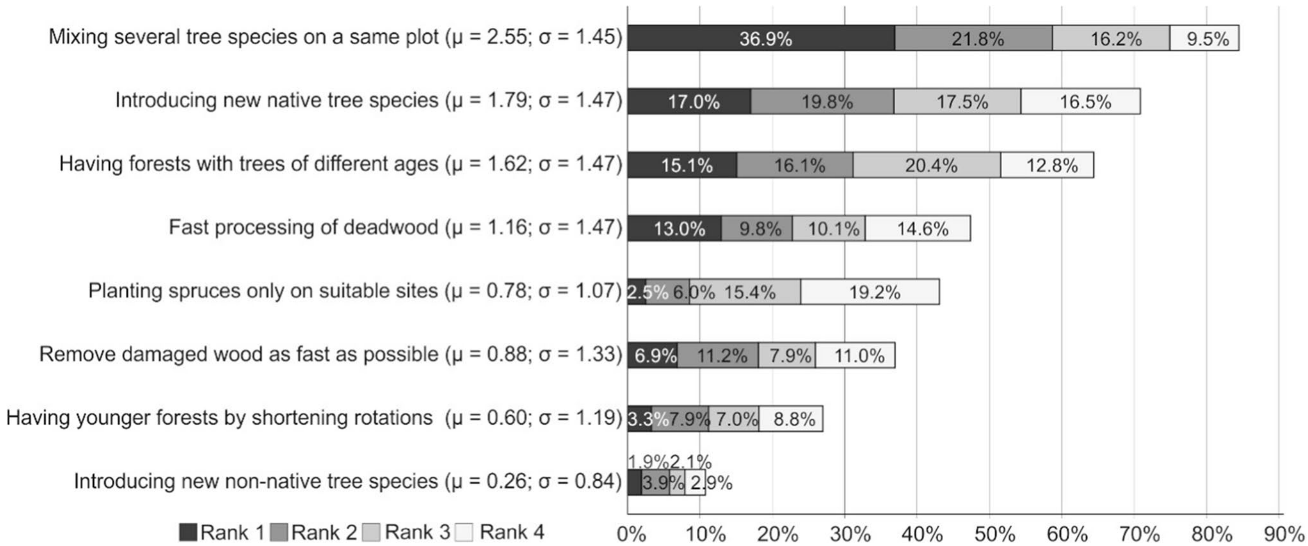


Fig. 3 Ranking of adaptation strategies against forest dieback (based on frequency of mention). *Note*: $N = 590$; rank 1 = most important to rank 4 = least important; mean calculation: 0 = not important at all to 4 = most relevant

More than half of the respondents (top-two box value 52.0%) state that there are already consequences of climate change in the study area. This notion significantly correlates with the personal experience with climate change ((χ^2 ($N = 452$) = 33.4***; Cramérs $V = 0.271$***).

In the study areas, especially drier summers (82.4%) and warmer winters (76.1%) were strongly recognized. More forest fires were least noticed, nevertheless reaching a 50.1% top-two box value. Focusing on the forests in the study areas, forest damages in mountain forests are not a new phenomenon and they were already perceived in the past in the Bavarian Forest as well as the German Alps (72.3%). This high level of consciousness notwithstanding, about one-quarter of the respondents (23.2%) state that forest damages have not occurred until today. In relation to climate change, 46% of the respondents think that the forests in the study areas in particular are currently affected by climate change, with an additional 36.5% opting for the answer category "medium" and only less than one-fifth (17.5%) denying climate change impacts on the forests.

The most strongly perceived climate change impacts on forests at present are damages caused by insects or pest outbreaks (69.6% top-two box values; mean 3.87; SD 0.98), an increase in tree mortality (57.1%; mean 3.55; SD 1.02) and forest landscape degradation (57.0%; mean 3.52; SD 1.02). Asked whether they think that forests in the survey area will be affected by climate change from now to 2050, 85.7% (strongly) agree, while only 3.3% reject this notion.

This is in line with the aggregated variable *climate change perception*, which shows that the respondents are quite aware of climate change (60.8%; mean 3.60; SD 0.71), with the largest shares for the answer categories of "quite" (55.0%) and "partly" (32.5%). Only one respondent does not perceive climate change at all. There are no significant differences in climate change perception between the Bavarian Forest (mean 3.55; SD 0.72) and the German Alps (mean 3.62; SD 0.70; t-value = − 1.047).

The lower part of Fig. 2 depicts the relationship between *climate change perception* and the dimensions of van der Linden's (2015) CCPRM model: Similar to the forest dieback perception, both the cognitive dimension and the experiential processing are positively related to the climate change perception: the higher the state of knowledge about climate change and the stronger that participants individually perceive climate change, the stronger the aggregated climate change perception. Regarding the socio-cultural dimension, an ecocentric environmental worldview positively coincides with climate change perception, while by contrast an anthropocentric environmental worldview is negatively related. The socio-demographic dimension is not significantly correlated with climate change perception.

Finally, Fig. 2 also illustrates that there is a highly significant and medium to strong positive correlation between both aggregated constructs, climate change and forest dieback perception ($r_s = 0.600$***). This means that the stronger the forest dieback perception, the stronger the perception of climate change, and vice versa.

Preferences regarding mountain forest adaptation strategies

According to the respondents, mixing several tree species in the same stand (selected by 84.4% of the respondents; mean 2.55; SD 1.45) and introducing new suitable native tree species (70.8%; mean 1.79; SD 1.47) are the most preferred adaptation strategies against forest dieback (Fig. 3). Having forests

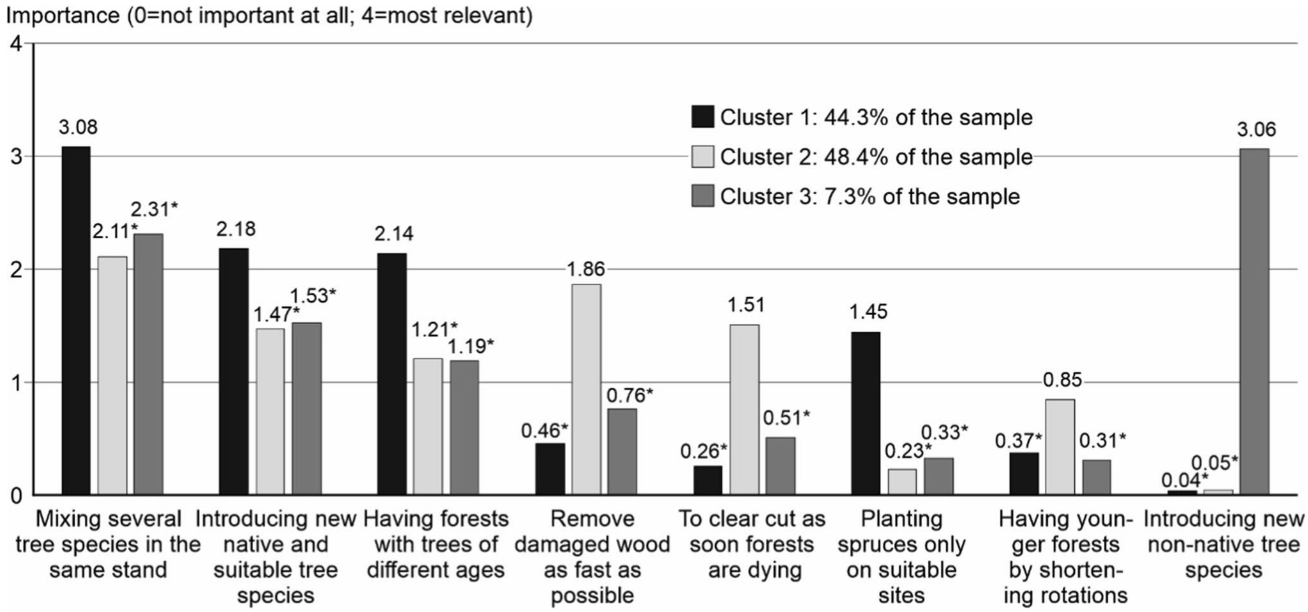


Fig. 4 Cluster of respondents based on preferred forest adaptation strategies. *Note*: $N=590$; rank 1 = most important to rank 4 = least important; mean calculation: 0 = not important at all to 4 = most relevant; * indicates that values are not significantly different at the $p<0.05$ level according to Tamhane T2 post-hoc test

with trees of different ages reaches a mean of 1.62 (64.4%; SD 1.47). The least preferred strategies are salvage logging, i.e., removing damaged wood as fast as possible (37.0%; mean 0.88; SD 1.33), shortening rotation periods (27.0%; mean 0.60; SD 1.19) and introducing new non-native tree species (10.8%; mean 0.26; SD 0.84).

Planting spruces only on better-suited sites was ranked as less relevant by forest owners (mean 0.48; SD 0.92) than by non-forest owners (mean 0.81; SD 1.08; *t*-value = − 2.33*). Salvage logging was ranked by forest owners as more relevant (mean 1.62; SD 1.62) than by non-forest owners (mean 1.11; SD 1.45; *t*-value = 2.29*).

A cluster analysis of the respondents (Fig. 4) resulted in three quite different groups. Respondents grouped in cluster 1 ($n=261$; 44.3% of the sample) prefer rather nature-oriented forestry including having the strongest preferences for mixed forests, cultivating native tree species, having forests with trees of different ages as well as spruce only on suitable stands. The fast removal of infested trees and salvage logging are least supported compared to the other clusters.

Members of the largest cluster 2 ($n=285$; 48.4%) prefer a more traditional forestry including mixed forests as most preferred strategy, while the quick removal of infested trees is nearly as important, followed by salvage logging ("to clear cut as soon as forests are dying"). Cultivating native tree species are only ranked fourth. The shortening of rotation periods has the highest level of agreement in this cluster. In contrast to cluster 1, members of this cluster agree significantly more with anthropocentric environmental worldview, while their climate change perception is lowest, marking a significant difference compared to cluster 3. Members of cluster 2 have a slightly lower educational and income level compared to clusters 1 and 3.

Cluster 3 is a rather small group ($n=43$; 7.3%), whose members strongly prefer introducing new non-native tree species (e.g., Douglas fir) in contrast to clusters 1 and 2. For the strategies ranked second to fourth, cluster 3 members show similar preferences to cluster 2. Regarding the removal of infested trees, salvage logging and shortening of rotations, these strategies are least preferred similarly to cluster 1. Cluster 3 members have the highest climate change perception.

Regarding the forest dieback perception, no significant differences could be revealed between the clusters. Similarly, we found no differences between forest owners and the other respondents regarding cluster membership (but between members of forest owner associations and non-members), while the two survey areas show slight divergences (Cramer's *V* 0.160, $p<0.001$): Bavarian Forest inhabitants are overrepresented in clusters 2 and 3, while respondents from the German Alps are overrepresented in cluster 1.

Discussion and conclusion

We contribute to the literature by closing the research gap about the nexus between public perceptions of forest dieback and climate change by providing empirical evidence from two Southern German mountain areas. Our results show that forest dieback is not perceived as a new phenomenon in the Bavarian

Forest and the German Alps. However, climate change is now perceived as the second most important influencing factor on forests, preceded by pests, diseases and invasive species, which are themselves fostered by climate change. This is in line with the results of a Delphi study by Sacher and Mayer (2019) in which forest experts named climate change as the most important influencing factor on forest development in Bavaria for the next three to six decades. The higher perception of pests, disease and invasive species in the Bavarian Forest fits very well with the long-term issue of bark beetle outbreaks in the same region (Kölling 2008; Müller et al. 2008; Binder and Höllerl 2011; Triebenbacher and Lobinger 2020). Given the setting in two mountain areas, our results indicate that climate change is not only perceived by urban elites but also in rural, partly peripheral and economically disadvantaged regions. Forest dieback seems to serve as means for inhabitants of rural, forest-dominated regions to experience the impacts of climate change. The climate change perception of rural residents might be crucial for their approval of the transition to renewable energies with considerable landscape impacts especially in rural areas (e.g., massive increase in wind turbines and solar power stations etc.).

While public risk perceptions are clearly complex and multi-dimensional (Renn and Rohrmann 2000), past research has suggested that risk perceptions of climate change are primarily influenced by four key dimensions, namely experiential processing, cognitive, socio-cultural, and socio-demographic factors (van der Linden 2015). Our study underpins both forest dieback and climate change perception by several variables of the theoretical CCRP model (van der Linden 2015). Experiential processing plays an important role: the more strongly that participants state being affected by climate change—i.e., having already individually experienced climate change—the more they perceive forest dieback. Soucy et al. (2021) derived similar results for forest stakeholders, with knowledge about climate change, personal experience and social norms being key determinants of climate change risk perception.

More than 90% of the respondents think that climate change is real, even though the majority of them have not yet been personally affected by climate change. Thus, the proportion of respondents in the Bavarian Forest and the German Alps who regard climate change as real is higher than in 2013 (Osberghaus et al. 2013), and consistent with a survey in 2021, where 91.8% of respondents state climate change as real (Frondel et al. 2021). Frondel et al. (2021) found an increase in the perceived importance of climate change issues in Germany from 2015.

Climate is a statistical phenomenon that describes average weather conditions over a period of 30 years and therefore cannot be easily and accurately identified by the lay public (Weber 2010; IPCC 2013). Thus, climate and climate change are mainly perceivable by secondary indicators such as drier summers and warmer winters, drought (Iglesias 2021), glacier melt (Salim et al. 2023) and an increase in forest damages and tree mortality in the forest dieback context. This indicates that experiential processing is important for human climate change perception. This result is in line with, e.g., Diakakis et al. (2021), who found that climate-related disaster experience influences climate change perception for the Eastern Mediterranean (Greece). Iglesias (2021) revealed that a local experience-driven risk perception supports adaptation actions. Further, Sousa-Silva et al. (2018) even found a weak but significant positive association between forest owners' and managers' individual experiences with climate change and the silvicultural adaptive response, which is also shaped by the perception of climate change. Thus, our results underline that forest dieback serves as a sign of climate change and increases its perception by serving as a catalyst of climate change perception.

In addition to experiences in and with the environment, influencing factors like environmental worldview or information level affect the perception. Due to moral obligations and responsibility, ecocentric respondents perceive climate change and its effects stronger than respondents with an anthropocentric environmental worldview (Heimann 2019). Moreover, Whitmarsh (2011) demonstrates that climate change beliefs are fundamentally linked to values and worldviews and that citizens with low pro-environmental values tend to be more skeptical about the reality and severity of climate change. In an EU-wide study on images and values of nature, Farjon et al. (2016) summarize that the majority of the European population have an ecocentric attitude (60%) and one-quarter an anthropocentric attitude. However, in most cases, respondents did not show a strong preference for a particular environmental attitude. In the Bavarian Forest and the German Alps, the majority of respondents (55%) can also be classified as ecocentric, and about 19% can be classified as anthropocentric. However, there are no clear preferences for a particular environmental worldview either.

Regarding the cognitive dimension, the better that respondents estimate their state of knowledge about both climate change and forests, the more that they perceive forest dieback. This fact makes sense as forest dieback is not always noticeable upon first glance and knowledge about forests and climate change and regular visits are required to assess the state of the forests. In some cases, forest dieback looks like a slow-burning crisis (Staupe-Delgado 2019). Blennow et al. (2016) found that forest stakeholders with a high educational level were more concerned about climate change than those without. Moreover, Archie (2014) found that the more informed that respondents were about climate change, the higher their concern about and belief in climate change, and the more likely they were to report current adaptation planning or implementation.

If the respondents regard deadwood as a source of danger for forest visitors and ecologically important, they perceive forest dieback more strongly. Thus, it seems that the perception of forest dieback does not depend on an either negative or positive overall attitude towards deadwood but on differing aspects of the complex attitudes towards deadwood (see also Sacher 2020). Müller (2011) highlights that people often identify with the visual image of a "thick, green forest" landscape that creates a shared sense of place and belonging. The author argues that it is unsurprising when forest disturbances and resulting high amounts of deadwood have profound social repercussions. Indeed, the occurrence of deadwood as a result of bark beetle outbreaks has led to various emotional debates and conflicts in the Bavarian Forest National Park over recent decades (see, e.g., Liebecke et al. 2011; von Ruschkowski and Mayer 2011). By contrast, several more recent studies also indicate that deadwood in general does not have a negative image among the population (Rathmann et al. 2020; Sacher 2020; Sacher et al. 2022).

The cluster analysis revealed three quite different groups: Respondents with a preference for rather nature-oriented forestry, a more traditional forestry, and those who strongly prefer introducing new non-native tree species. However, mixed forests is the most important strategy in two of the three clusters. Bavarian Forest inhabitants are overrepresented in the second cluster, while respondents from the German Alps are overrepresented in the first cluster, possibly due to the more pronounced forest dieback and bark beetle outbreaks in the Bavarian Forest and/or the important role of forestry and wood-processing industries there in the past (see section "Study areas"). Cultivating a mixed and uneven-aged forest is not a new concept but is gaining new attention with the climate change discourse (Matthes et al. 2014; Juutinen et al. 2020). While inhabitants prefer the prospective forest state with mixed, structured forests with native species—which is also recommended by forest policies (BMEL 2021) and researchers (Hilmers et al. 2020)—forest stakeholders realize several obstacles to adaptation like a lack of knowledge and information (Sousa-Silva et al. 2018; Hengst-Erhart 2019; Mostegl et al. 2019; Deuffic et al. 2020; Pröbstl-Haider et al. 2020). Peterson St-Laurent et al. (2018) found greater levels of support for rehabilitation strategies, and lesser levels for conservation-focused strategies, in contrast to enhanced forest management strategies by the British Columbian public. As we found in our study, the support for forest management strategies is thereby affected by environmental worldviews and risk perception, but also by socio-demographic factors.

We conclude that the public in the Bavarian Forest and the German Alps largely appreciates mixed, diverse and structured forests with native tree species. In this way, our results support the current Bavarian forest policy programs (StMELF 2019, 2020) and the German Federal Forest Strategy 2050 (BMEL 2021) and are in line with a recent quantitative study in Bavaria by Sacher et al. (2022) and the opinion of pro-active forest stakeholders (Deuffic et al. 2020; Garms 2021). By contrast, forest policies like the declaration of Moritzburg (German Forestry Ministers 2019)—which suggest "salvage logging" of damaged trees to prevent bark beetle impacts—are at odds with the public's preferred forest adaptation strategies towards climate change and thus could lead to conflicts. In addition, such strategies might lead to negative impacts on forest biodiversity (Thorn et al. 2019).

Our findings underline the importance of understanding local perceptions of forest dieback and climate change as we found that these perceptions are affected by individual experiences with climate change, the knowledge level about forests and climate change, and the environmental worldviews and deadwood attitudes. Similarly, the support for forest management strategies is affected by environmental worldviews and risk perception, but also by socio-demographics. All these influencing factors could vary considerably between different regions. This implies for forest management seeking acceptance and support for climate change adaptation measures that decision-makers of all spatial levels (federal state, state forests, local foresters, forest owner associations) must transparently inform the (local) population about their strategies and measures and should tailor their outreach to the different stakeholder groups keeping in mind their differing perceptions of nature. This need for targeted communication strategies is further highlighted by our results which also reveal important misconceptions held by the public: Given that a considerable share of the respondents named tourism and recreationists' behavior as main risks to forests, all relevant forest stakeholders need to better inform the public about the climate change related risks for forests, which are overall much more salient and severe compared to the rather locally concentrated negative impacts of tourism on forests. It should be explained to lay people how climate change and its direct and indirect consequences impact forests already now and will do so even more in the future and which adaptation strategies leading to which effects and landscape consequences are being pursued by decision-makers. An important prerequisite for an environment that promotes learning is to create situations which are characterized by openness, in which parties (e.g., forest owners, public) exchange valuations and assessments, and thereby fill in their personal knowledge maps (Blennow et al. 2014). One example of such targeted communication could be that the forest owners (often mountain farmers but also the regional state forest agencies, see Eriksson 2017) regularly offer short hiking tours through forest areas especially impacted by forest dieback or where adaptation measures already take place. In this way, they could share first-hand their experiences about the impacts of climate change on the local mountain forests, explain their strategies and discuss the pros and cons with the participants. This format may be also an ideal way to promote discussion and exchange under small scale forest owners and forestry experts providing advisory services (e.g., forest owner associations and authorities). Blennow et al. (2014) and Vulturius et al. (2020) found that especially peers are valuable in connecting information about climate risks and adaptation to the actual forest property. Female forest owners and foresters could organize special gatherings to communicate forest dieback issues to the female population otherwise potentially put off by the male dominance in the forest sector (Süddeutsche Zeitung 2023). In addition, short videos highlighting current issues could be produced by the forestry actors and shared on social media and with teachers to reach the younger generations in the mountain municipalities and beyond. Moreover, commonly used information sources like articles in local newspapers may be a good way to reach a broader audience (including small scale forest owners, see Soucy et al. 2020).

To sum up, the implemented CCRP model has been validated by similar studies (e.g., Grothmann and Patt 2005; Whitmarsh 2011; Soucy et al. 2021) and enables the combined analysis of climate change and forest dieback perception. Nearly two-thirds of the respondents in two mountain areas of Southern Germany perceive moderate to strong forest dieback in mountain forests and relate it to the similar strongly perceived climate change. Consequently, forest dieback and climate change perception are positively correlated. Thus, it could be interpreted that forest dieback serves as an indicator for hardly perceivable long-term impacts of climate change. Nevertheless, the causal relation between both constructs must be object of further research as it may well be the case that the perception of both constructs is driven by similar antecedents (e.g., values, experiences). However, the correlations in the CCRP model are rather weak (which should be reanalyzed in future research), possibly caused by a too low level of knowledge of the respondents (lay people, not forestry experts)—Agbenyega et al. (2009) also address this lack of knowledge among forest stakeholders. Further reasons could be that some of our variables are not salient regarding risk perceptions and would need to be replaced in future studies. Further limitations of this study are its setting in two specific rather rural areas, whereby its results may not be generalizable to the whole of Bavaria or Germany. In addition, our survey was conducted in summer/fall 2018, when attention to drought and climate change in Germany was not as pronounced as in the following years (Lübke 2021), among others due to the media attention to the "Fridays for Future" youth protest movement. Thus, perceptions of forest dieback and climate change are likely to have changed in the meantime.

While the theoretical model of van der Linden (2015) was able to explain the perceptional process of climate change and forest dieback, we found no correlations between the perceptions and the preferences for silvicultural adaptation measures which should be reexamined by future research. Respondents support nature-based forest adaptation strategies over intense measures but show a considerable heterogeneity in their preferences as revealed through a cluster analysis. Based on this study, further research could focus on other mountain forests or other regions in general to enable a comprehensive analysis of forest dieback and climate change perception in and beyond mountain areas.

Appendix

See Tables 5 and 6.

Table 5 Factor analysis of environmental worldview

	Component		
	anthropocentric	holistic	ecocentric
Rotated Component Matrix[a]			
Q12 a: Vulnerable nature areas should be closed to leisure and recreational activities	− 0.455	**0.602**	0.162
Q12 b: We should use nature in such a way that we get the most economic value from it	**0.723**	0.136	0.324
Q12 c: Too much emphasis has been placed on nature conservation	**0.750**	0.014	− 0.178
Q12 d: Hunting is cruel and inhumane to animals	− 0.001	0.037	**0.859**
Q12 e: It is natural that wild animals sometimes starve to death or are injured by other animals, and we should accept that	0.007	**0.586**	− 0.516
Q12 f: Trees may be felled if needed to increase the diversity of species in a forest	0.306	**0.779**	0.010

64.7% of the total variance are explained

Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization

[a]Rotation converged in 5 iterations

Table 6 Socio-demographic characteristics of the sample

Gender	
Female	52.3%
Male	47.7%
Age in years	
Average	51.2
Median	52.0 (SD 15.0)
Educational level	
Still in school	0%
General secondary school	17.9%
Intermediate secondary school	43.2%
A-level or similar	38.9%
Vocational training or (technical) university degree	
Yes	70.9%
No	29.1%
Monthly net household income	
0–499€	0.8%
500€–999€	3.6%
1000€–1499€	9.3%
1500€–1999€	14.3%
2000€–2499€	15.7%
2500€–2999€	13.9%
3000€–3499€	15.0%
3500€–3999€	8.3%
4000€–4499€	6.5%
4500€–4999€	5.1%
5000€ or more	7.7%
Professional situation	
Independent	7.9%
Top manager (senior official, top executive)	7.1%
Craftsman (manual worker, skilled worker)	14.7%
Other official, other employee	26.3%
Farmer or forester, full time	0.6%
Farmer or forester, part time	0.3%
Housewife/-man	5.5%
Pupil, student, trainee	2.9%
Unemployed	2.2%
Retiree, pensioner	30.0%
Other	2.6%
Professional relation to forestry	
Yes	3.5%
No	96.5%
Forest owner	
Yes	8.1%
No	91.9%
Member of an association	
Environmental protection	10.2%
Forest owner	3.5%
Hunting or fishing	3.8%

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References

Agbenyega O, Burgess PJ, Cook M, Morris J (2009) Application of an ecosystem function framework to perceptions of community woodlands. Land Use Policy 26:551–557. https://doi.org/10.1016/j.landusepol.2008.08.011

Allen C (2009) Climate-induced forest dieback: an escalating global phenomenon? Unasylva 60(231/232):43–49

Akerlof K, Maibach EW, Fitzgerald D, Cedeno AY, Neuman A (2013) Do people "personally experience" global warming, and if so how, and does it matter? Glob Environ Change 23(1):81–91. https://doi.org/10.1016/j.gloenvcha.2012.07.006

Ammer C (2009) Welche Baumarten trotzen dem Klimawandel? In: Agrar-Bündnis EV (ed) Der kritische Agrarbericht. ABL-Verlag, München, pp 199–203

Archie KM (2014) Mountain communities and climate change adaptation: barriers to planning and hurdles to implementation in the Southern Rocky Mountain Region of North America. Mitig Adapt Strategy Glob Change 19:569–587. https://doi.org/10.1007/s11027-013-9449-z

Bałazy R, Zasada M, Ciesielski M, Waraksa P, Zawila-Niedzwieckie T (2019) Forest dieback processes in the Central European Mountains in the context of terrain topography and selected stand attributes. For Ecol Manag 435:106–119. https://doi.org/10.1016/j.foreco.2018.12.052

Bässler C (2008) Climate change—trend of air temperature in the Innerer Bayerischer Wald (Bohemian Forest). Silva Gabreta 14:1–18

Bätzing W (2015) Die Alpen. Geschichte und Zukunft einer europäischen Kulturlandschaft, 4th edn. C.H. Beck, München

Bavarian State Institute of Forestry (LWF) (2001) Die regionale natürliche Waldzusammensetzung Bayerns. LWF, Freising

Bavarian State Ministry of Food, Agriculture and Forests (StMELF) (2016) Bavarian forest administration—ready to meet future challenges. StMELF, München

Bavarian State Ministry of Food, Agriculture and Forests (StMELF) (2019) Acht-Punkte-Programm für zukunftsfähige Wälder in Bayern. https://www.stmelf.bayern.de/wald/forstpolitik/wald-im-klimawandel/225352/index.php Accessed 07 Aug 2022

Bavarian State Ministry of Food, Agriculture and Forests (StMELF) (2020) Waldbericht 2020. StMELF, München

Bavarian State Ministry of the Environment and Consumer Protection (StMUV) (2015) Klima-Report Bayern 2015. Klimawandel, Auswirkungen, Anpassungs- und Forschungsaktivitäten. StMUV, München

Bayerisches Landesamt für Statistik (LfSta) (2023a) Bevölkerungsentwicklung in den kreisfreien Städten und Landkreisen Bayerns. https://www.statistik.bayern.de/mam/statistik/gebiet_bevoelkerung/demographischer_wandel/0108_karte_bevoelkerungsentwicklung.png

Bayerisches Landesamt für Statistik (LfSta) (2023b) Volkswirtschaftliche Gesamtrechnungen: Kreise, Bruttoinlandsprodukt je Einwohner/Bruttoinlandsprodukt je Erwerbstätigen, Jahre Kreisberechnungen Bruttoinlandsprodukt je Einwohner (EUR) Jahr 2018. https://www.statistikdaten.bayern.de/genesis

Binder F, Höllerl S (2011) Bayerische Alpen – ein denkbares Rückzugsgebiet für die Fichte im Klimawandel? LWF Wissen 80:108–113

Blennow K, Persson J, Wallin A, Varemann N, Persson E (2014) Understanding risk in forest ecosystem services: implications for effective risk management, communication and planning. Forestry 87:219–228. https://doi.org/10.1093/forestry/cpt032

Blennow K, Persson J, Persson E, Hanewinkel M (2016) Forest owners' response to climate change: university education trumps value profile. PLoS ONE 11(5):1–13. https://doi.org/10.1371/journal.pone.0155137

Bolte A, Ammer C, Löf M, Madsen P, Nabuurs G, Schall P, Spathelf P, Rock J (2009) Adaptive forest management in central Europe: Climate change impacts, strategies and integrative concept. Scand J For Res 24(6):473–482. https://doi.org/10.1080/02827580903418224

Brahic E, Garms M, Deuffic P, Lyser S, Mayer M (2022) How do inhabitants of mountain areas perceive climate change and forest dieback? A comparison between France and Germany. Environ Manag 70(6):896–910. https://doi.org/10.1007/s00267-022-01694-9

Brody SD, Zahran S, Vedlitz A, Grover H (2007) Examining the relationship between physical vulnerability and public perceptions of global climate change in the United States. Environ Behav 40(1):72–95. https://doi.org/10.1177/0013916506298800

Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) (2018) Laufende Raumbeobachtung – Raumabgrenzungen, Siedlungsstrukturelle Kreistypen. https://www.bbsr.bund.de/BBSR/DE/forschung/raumbeobachtung/Raumabgrenzungen/deutschland/kreise/siedlungsstrukturelle-kreistypen/kreistypen.html;jsessionid=1D26BC6CA9BB964F79E3635196ED0326.live21303

Bundesministerium für Ernährung und Landwirtschaft (BMEL) (2021) Waldstrategie 2050. BMEL, Bonn

Burger H (2003) Der Bayerische Wald. Linien einer Landschaft. Morsak, Grafenau

Chang W-Y, Van Lanitz A, Maclean DA (2009) Public attitudes about forest pest outbreaks and control: case studies in two Canadian provinces. For Ecol Manag 257(4):1333–1343. https://doi.org/10.1016/j.foreco.2008.11.031

Capstick S, Whitmarsh L, Poortinga W, Pidgeon N, Upham P (2015) International trends in public perceptions of climate change over the past quarter century. Wiley Interdiscip Rev Clim Change 6(1):35–61. https://doi.org/10.1002/wcc.321

Deuffic P, Garms M, He J, Brahic E, Yang H, Mayer M (2020) Forest dieback, a tangible proof of climate change? A cross-comparison of forest stakeholders' perceptions and strategies in the mountain forests of Europe and China. Environ Manag 66:858–872. https://doi.org/10.1007/s00267-020-01363-9

Diakakis M, Skordoulis M, Savvidou E (2021) The Relationships between public risk perceptions of climate change, environmental sensitivity and experience of extreme weather-related disasters: evidence from Greece. Water 13:2842. https://doi.org/10.3390/w13202842

Echvarren JM, Balzekiene A, Telesiene A (2019) Multilevel analysis of climate change risk perception in Europe: natural hazards, political contexts and mediating individual effects. Saf Sci 120:813–823. https://doi.org/10.1016/j.ssci.2019.08.024

Ellenberg H, Leuschner C (2010) Vegetation Mitteleuropas mit den Alpen in ökologischer, dynamischer und historischer Sicht. UTB, Stuttgart

Eriksson L (2017) Components and drivers of long-term risk communication: exploring the within-communicator, relational, and content dimensions in the Swedish forest context. Organ Environ 30(2):162–179. https://doi.org/10.1177/1086026616649647

European Commission (EC) (2009) Europeans' attitudes towards climate change: Eurobarometer 313. European Union, Brussels. http://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs_300_full_en.pdf Accessed 02 Aug 2022

Farjon H, Blaeij A, Boer T, Langers F, Vader J, Bujis A (2016) Citizens' images and values of nature in Europe. A survey in nine EU Member States. PBL Netherlands Environmental Assessment Agency, Den Haag

Fellenor J, Barnett J, Potter C, Urquhart J, Mumford JD, Quine CP (2019) Ash dieback and other tree pests and pathogens: dispersed risk events and the social amplification of risk framework. J Risk Res 312(2):1–20. https://doi.org/10.1080/13669877.2018.1485170

Fickert T (2018) Der deutsche Alpenraum. Historische Landschaftsentwicklung und aktuelle Herausforderungen. Geogr Rundsch 70(5):4–11

Frick J, Bauer N, von Lindern E, Hunziker M (2018) What forest is in the light of people's perceptions and values: socio-cultural forest monitoring in Switzerland. Geogr Helv 73(4):335–345. https://doi.org/10.5194/gh-73-335-2018

Frondel M, Kükenthal VC, Larysch T, Osberghaus D (2021) Wahrnehmung des Klimawandels in Deutschland: Eine Längsschnittbefragung privater Haushalte. Z. Energ. Wirtsch. 45:119–131. https://doi.org/10.1007/s12398-021-00303-2

Frondel M, Simora M, Sommer S (2017) Risk perception of climate change: empirical evidence for Germany. Ecol Econ 137:173–183. https://doi.org/10.1016/j.ecolecon.2017.02.019

Fulda B, Hövermann A (2020) Soziale Lebenslagen und die Sorge über den Klimawandel. Befunde aus repräsentativen Bevölkerungsumfragen in 2017 und 2019 (=Working Paper Forschungsförderung No. 182). Hans-Böckler-Stiftung, Düsseldorf

Garms M (2021) Perception of climate-induced forest dieback and silvicultural adaptation to climate change in mountain forests—the case of the Bavarian Forest. Dissertation, University of Greifswald. https://nbn-resolving.org/urn:nbn:de:gbv:9-opus-45636

George JP, Burkner PC, Sanders TGM, Neumann M, Cammelleri C, Vogt JV, Lang M (2022) Long-term forest monitoring reveals constant mortality rise in European forests. Plant Biol 24(7):1108–1119. https://doi.org/10.1111/plb.13469

German Forestry Ministers (associated with the conservative party) (eds) (2019) Moritzburger Erklärung. Klimakrise: Masterplan für Deutschlands Wälder. Moritzburg. https://www.agrarheute.com/media/2019-08/moritzburger_erklaerung.pdf Accessed 07 Aug 2022

Goldberg MH, Van der Linden S, Leiserowitz A, Maibach E (2020) Perceived social consensus can reduce ideological biases on climate change. Environ Behav 52(5):495–517. https://doi.org/10.1177/0013916519853302

Grilli G, Jonkisz J, Ciolli M, Lesinski J (2016) Mixed forests and ecosystem services: investigating stakeholders' perceptions in a case study in the Polish Carpathians. For Policy Econ 66:11–17. https://doi.org/10.1016/j.forpol.2016.02.003

Grothmann T, Patt A (2005) Adaptive capacity and human cognition: the process of individual adaptation to climate change. Glob Environ Change 15(3):199–213. https://doi.org/10.1016/j.gloenvcha.2005.01.002

Grothmann T, Daschkeit A, Felgentreff C, Görg C, Horstmann B, Scholz I, Tekken V (2011) Anpassung an den Klimawandel - Potenziale sozialwissenschaftlicher Forschung in Deutschland. Gaia 20(2):84–90. https://doi.org/10.1016/j.gloenvcha.2005.01.002

Guo R, Li Y, Shang L, Feng C, Wang X (2021) Local farmer's perception and adaptive behavior toward climate change. J Clean Prod 287:125332. https://doi.org/10.1016/j.jclepro.2020.125332

Hartl-Meier C, Zang C, Dittmar C, Esper J, Göttlein A, Rothe A (2014) Vulnerability of Norway spruce to climate change in mountain forests of the European Alps. Clim Res 60(2):119–132. https://doi.org/10.3354/cr0122

Heimann T (2019) Culture, space and climate change: vulnerability and resilience in European coastal areas. Routledge, Abingdon

Helgeson J, Van der Linden S, Chabay I (2012) The role of knowledge, learning and mental models in public perceptions of climate change related risks. In: Wals AEJ, Corcoran PB (eds) Learning for sustainability in times of accelerating change. Academic Publishers, Wageningen, pp 329–346. https://doi.org/10.3920/978-90-8686-757-8_21

Hengst-Ehrhart Y (2019) Knowing is not enough: exploring the missing link between climate change knowledge and action of German forest owners and managers. Ann for Sci 76(4):179. https://doi.org/10.1007/s13595-019-0878-z

Hilmers T, Biber P, Knoke T, Pretzsch H (2020) Assessing transformation scenarios from pure Norway spruce to mixed uneven-aged forests in mountain areas. Eur J For Res 139(4):567–584. https://doi.org/10.1007/s10342-020-01270-y

Iglesias A, Garrote L, Bardaji I, Santillan D, Esteve P (2021) Looking into individual choices and local realities to define adaptation options to drought and climate change. J Environ Manag 293:112861. https://doi.org/10.1016/j.jenvman.2021.112861

Intergovernmental Panel on Climate Change (IPCC) (2013) Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Intergovernmental Panel on Climate Change (IPCC) (2020) Climate Change and Land. An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Summary for Policymakers. Bonn

Jackson J, Allum N, Gaskell G (2006) Bridging levels of analysis in risk perception research: the case of the fear of crime. Forum Qual Sozialforschung. https://doi.org/10.17169/fqs-7.1.63

Job H, Bittlingmaier S, Mayer M, von Ruschkowski E, Woltering M (2021) Park-people relationships: the socioeconomic monitoring of national parks in Bavaria, Germany. Sustainability 13(16):8984. https://doi.org/10.3390/su13168984

Juutinen A, Tolvanen A, Koskela T (2020) Forest owners' future intentions for forest management. For Policy Econ 118:102220. https://doi.org/10.1016/j.forpol.2020.102220

Keenan RJ (2015) Climate change impacts and adaptation in forest management: a review. Ann For Sci 72(2):145–167. https://doi.org/10.1007/s13595-014-0446-5

Keller R (2011) Diskursforschung: Eine Einführung für SozialwissenschaftlerInnen (=Qualitative Sozialforschung Vol. 14). VS Verlag für Sozialwissenschaften, Wiesbaden

Kemp KB, Blades JJ, Klos PZ, Hall TE, Force JE, Morgan P, Tinkham WT (2015) Managing for climate change on federal lands of the western United States: perceived usefulness of climate science, effectiveness of adaptation strategies, and barriers to implementation. Ecol Soc 20(2):17. https://doi.org/10.5751/ES-07522-200217

Klemmt HJ, Wauer A, Zimmermann L, Dietrich HP, Raspe S (2018) Zu nass, zu trocken, zu windig. Witterungsextreme stressen unsere Wälder im Klimawandel. LWF Aktuell 2:16–20

Köhl M, Plugge D, Gutsch M, Lasch-Born P, Müller M, Reyer C (2017) Wald und Forstwirtschaft. In: Brasseur G, Jacob D, Schuck-Zöller S (eds) Klimawandel in Deutschland: Entwicklung, Folgen, Risiken und Perspektiven. Springer, Berlin, pp 193–202

Kölling C, Zimmermann L, Walentowski H (2007) Klimawandel: Was geschieht mit Buche und Fichte? Entscheidungshilfen für den klimagerechten Waldumbau in Bayern. AFZ-DerWald 11:584–588

Kölling C (2008) Wälder im Klimawandel. Die Forstwirtschaft muss sich anpassen. In: Graßl H., Jendritzky G, Karbe L, Lozán J L, Reise K (eds) Warnsignal Klima. Gesundheitsrisiken - Gefahren für Menschen, Tiere und Pflanzen. Wiss. Auswertungen, Hamburg, pp 357–361

Korner C (2019) Mountain biodiversity, its causes and function: an overview. In: Korner C, Spehn EM (eds) Mountain biodiversity. A global assessment. Routledge, London, pp 3–20

Langner A, Irauschek F, Perez S, Pardos M, Zlatanov T, Öhman K, Nordström E-M (2017) Value-based ecosystem service tradeoffs in multi-objective management in European mountain forests. Ecosyst Serv 26(PartA):245–257. https://doi.org/10.1016/j.ecoser.2017.03.001

Laurent L, Buoncristiani J, Pohl B, Zekollari H, Farinotti D, Huss M, Mugnier J-L, Pergaud J (2020) The impact of climate change and glacier mass loss on the hydrology in the Mont-Blanc massif. Sci Rep 10:10420. https://doi.org/10.1038/s41598-020-67379-7

Leiserowitz A (2006) Climate change risk perception and policy preferences: the role of affect, imagery, and values. Clim Change 77(1–2):45–72. https://doi.org/10.1007/s10584-006-9059-9

Liebecke R, Wagner K, Suda M (2011) Die Akzeptanz des Nationalparks bei der lokalen Bevölkerung (Langfassung). Nationalparkverwaltung Bayerischer Wald, Grafenau

Lindner M, Maroschek M, Netherer S, Kremer A, Barbati A, Garcia-Gonzalo J, Seidl R, Delzon S, Corona P, Kolström M, Lexer M, Marchetti M (2010) Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For Ecol Manag 259(4):698–709. https://doi.org/10.1016/j.foreco.2009.09.023

Lübke C (2021) Wahrnehmung des Klimawandels als gesellschaftliches Problem. https://www.bpb.de/kurz-knapp/zahlen-und-fakten/datenreport-2021/umwelt-energie-und-mobilitaet/330375/wahrnehmung-des-klimawandels-als-gesellschaftliches-problem/. Accessed 06 Aug 2022

Lujala P, Lein H, Rod JK (2015) Climate change, natural hazards, and risk perception: the role of proximity and personal experience. Local Environ 20(4):489–509. https://doi.org/10.1080/13549839.2014.887666

Matthes U, Bieling C, Reeg T, Oelke M, Konold W (2014) Wie bewerten Akteure der Forst- und Holzwirtschaft den Klimawandel? Eine Untersuchung am Beispiel von Rheinland-Pfalz. Allg Forst Jagdztg 105(3/4):59–70

Mayer M (2013) Kosten und Nutzen des Nationalparks Bayerischer Wald: Eine ökonomische Bewertung unter Berücksichtigung von Tourismus und Forstwirtschaft. Oekom, München

Mayer M, Job H (2014) Die Bayerischen Alpen als Lebens- und Wirtschaftsraum zwischen Nutzungs- und Schutzansprüchen. In: Chilla T (ed) Leben in den Alpen. Verstädterung, Entsiedlung und neue Aufwertungen. Haupt, Bern, pp 33–49

McFarlane BL, Parkins JR, Watson DOT (2012) Risk, knowledge, and trust in managing forest insect disturbance. Can J for Res 42(4):710–719. https://doi.org/10.1139/X2012-030

Meinert T, Becker A, Bissolli P, Daßler J, Breidenbach J N, Ziese M (2019) Ursachen und Folgen der Trockenheit in Deutschland und Europa ab Juni 2019. https://www.dwd.de/DE/leistungen/besondereereignisse/duerre/20190712_trockenheit_juni_juli_2019.pdf?__blob=publicationFile&v=1. Accessed 07 Aug 2022

Menny C, Osberghaus D, Pohl M, Werner U (2011) General Knowledge about Climate Change, Factors Influencing Risk Perception and Willingness to Insure (=ZEW Discussion Papers No. 11–060). ZEW, Mannheim

Milfont TL (2012) The interplay between knowledge, perceived efficacy, and concern about global warming and climate change: a one-year longitudinal study. Risk Anal 32(6):1003–1020. https://doi.org/10.1111/j.1539-6924.2012.01800.x

Morris JL, Cottrell S, Fettig CJ, Hansen WD, Sherriff RL, Carter VA, Clear JL, Clement J, DeRose RJ, Hicke JA, Higuera PE, Mattor KM, Seddon AWR, Seppä HT, Stednick JD, Seybold SJ (2017) Managing bark beetle impacts on ecosystems and society: priority questions to motivate future research. J Appl Ecol 54(3):750–760. https://doi.org/10.1111/1365-2664.12782

Moser SC (2010) Now more than ever: the need for more societally relevant research on vulnerability and adaptation to climate change. Appl Geogr 30(4):464–474. https://doi.org/10.1016/j.apgeog.2009.09.003

Mostegl NM, Pröbstl-Haider U, Jandl R, Haider W (2019) Targeting climate change adaptation strategies to small-scale private forest owners. For Policy Econ 99:83–99. https://doi.org/10.1016/j.forpol.2017.10.001

Müller M (2011) How natural disturbance triggers political conflict: bark beetles and the meaning of landscape in the Bavarian Forest. Glob Environ Change 21(3):935–946. https://doi.org/10.1016/j.gloenvcha.2011.05.004

Müller M, Mayer M, Job H (2008) Totholz und Borkenkäfer im Nationalpark Bayerischer Wald aus touristischer Perspektive. In: Job H (ed) Die Destination Nationalpark Bayerischer Wald als regionaler Wirtschaftsfaktor. Nationalparkverwaltung Bayerischer Wald, Grafenau, pp 100–116

Oltedal S, Moen BE, Klempe H, Rundmo T (2004) Explaining risk perception: an evaluation of cultural theory. Rotunde, Trondheim

Osberghaus D, Schwirplies C, Ziegler A (eds) (2013) Klimawandel in Deutschland: Risikowahrnehmung, Wissensstand und Anpassung in privaten Haushalten. Ergebnisse einer Befragung deutscher Haushalte 2012. ZEW, Mannheim

Peterson St-Laurent G, Hagerman S, Kozak R, Hoberg G (2018) Public perceptions about climate change mitigation in British Columbia's forest sector. PLoS ONE 13(4):e0195999. https://doi.org/10.1371/journal.pone.0195999

Pidgeon N, Fischhoff B (2011) The role of social and decision sciences in communicating uncertain climate risks. Nat Clim Change 1(1):35–41. https://doi.org/10.1038/nclimate1080

Poortinga W, Whitmarsh L, Steg L, Böhm G, Fisher S (2019) Climate change perceptions and their individual-level determinants: a cross-European analysis. Glob Environ Change 55:25–35. https://doi.org/10.1016/j.gloenvcha.2019.01.007

Pröbstl-Haider U, Mostegl NM, Haider W (2020) Small-scale private forest ownership: understanding female and male forest owners' climate change adaptation behaviour. For Policy Econ 112:102111. https://doi.org/10.1016/j.forpol.2020.102111

Ranacher L, Lähtinen K, Järvinen E, Toppinen A (2017) Perceptions of the general public on forest sector responsibility: a survey related to ecosystem services and forest sector business impacts in four European countries. For Policy Econ 78:180–189. https://doi.org/10.1016/j.forpol.2017.01.016

Rathmann J, Sacher P, Volkmann N, Mayer M (2020) Using the visitor-employed photography method to analyse deadwood perceptions of forest visitors: a case study from Bavarian Forest National Park, Germany. Eur J For Res 139:431–442. https://doi.org/10.1007/s10342-020-01260

Renn O, Rohrmann B (2000) Cross-cultural risk perception: state and challenges. In: Renn O, Rohrmann B (eds) Cross-cultural risk perception: a survey of empirical studies. Springer, Boston, pp 211–233

Richins H (2016) Experience provision in mountain tourism: overview, contextual development and emphasis. In: Richins H, Hull JS (eds) Mountain tourism: experiences, communities, environments and sustainable futures. Cabi, Wallingford, pp 13–24

Rüdisser J, Schirpke U, Tappeiner U (2019) Symbolic entities in the European Alps: perception and use of a cultural ecosystem service. Ecosyst Serv 39:100980. https://doi.org/10.1016/j.ecoser.2019.100980

Rudman LA, McLean MC, Bunzl M (2013) When truth is personally inconvenient, attitudes change: the impact of extreme weather on implicit support for green politicians and explicit climate-change beliefs. Psychol Sci 24(11):2290–2296. https://doi.org/10.1177/0956797613492775

Ruhm W (2017) Waldbauliche Möglichkeiten in Zeiten des Klimawandels. In: BfW), (ed) Bundesforschungszentrum für Wald. Wege zum klimafitten Wald. BFW-Praxisinformation, Wien, pp 14–18

Ruiz I, Faria SH, Neumann MB (2020) Climate change perception: driving forces and their interactions. Environ Sci Policy 108:112–120. https://doi.org/10.1016/j.envsci.2020.03.020

von Ruschkowksi E, Nienaber B (2016) Akzeptanz als Rahmenbedingung für das erfolgreiche Management. Raumforsch Raumordn 74:525–540. https://doi.org/10.1007/s13147-016-0429-0

von Ruschkowksi E, Mayer M (2011) From conflict to partnership? Interactions between protected areas, local communities and operators of tourism enterprises in two German national park regions. J Tour Leisure Stud 17(2):147–181

Sacher P, Kaufmann S, Mayer M (2017) Wahrnehmung der natürlichen Waldentwicklung im Nationalpark Harz durch Besucher. Eine Befragung an Standorten mit unterschiedlicher Totholzexposition. Naturschutz und Landschaftsplanung 49(9):291–299

Sacher P, Mayer M (2019) Szenarien der Waldentwicklung in Bayern bis 2045 und 2075 – Ergebnisse einer Delphi-Studie mit ausgewählten Waldexperten. Institut für Geographie und Geologie, Greifswald. https://doi.org/10.23689/fidgeo-3258

Sacher P (2020) Wahrnehmung und ökonomische Bewertung waldbasierter kultureller Ökosystemleistungen mit und ohne Erholungsbezug durch die bayerische Bevölkerung. Goltze, Göttingen

Sacher P, Meyerhoff J, Mayer M (2022) Evidence of the association between deadwood and forest recreational site choices. For Policy Econ 135:102638. https://doi.org/10.1016/j.forpol.2021.102638

Salim E, Mayer M, Sacher P, Ravanel L (2023) Visitors' motivations to engage in glacier tourism in the European Alps: comparison of six sites in France, Switzerland, and Austria. J Sustain Tour 31(6):1373–1393. https://doi.org/10.1080/09669582.2022.2044833
Schirpke U, Tappeiner U, Tasser E (2019) A transnational perspective of global and regional ecosystem service flows from and to mountain regions. Sci Rep 9:6678. https://doi.org/10.1038/s41598-019-43229-z
Seidl R, Albrich K, Erb K, Formayer H, Leidinger D, Leitinger G, Tappeiner U, Tasser E, Rammer W (2019) What drives the future supply of regulating ecosystem services in a mountain forest landscape? For Ecol Manag 445:37–47. https://doi.org/10.1016/j.foreco.2019.03.047
Seidl R, Schelhaas M-J, Lexer MJ (2011) Unraveling the drivers of intensifying forest disturbance regimes in Europe. Glob Change Biol 17(9):2842–2852. https://doi.org/10.1111/j.1365-2486.2011.02452.x
Seidl R, Schelhaas M-J, Rammer W, Verkerk PJ (2014) Increasing forest disturbances in Europe and their impact on carbon storage. Nat Clim Change 4:806–810. https://doi.org/10.1038/nclimate2318
Senf C, Pflugmacher D, Zhiqiang Y, Sebald J, Knorn J, Neumann M, Hostert P, Seidl R (2018) Canopy mortality has doubled in Europe's temperate forests over the last three decades. Nat Commun. https://doi.org/10.1038/s41467-018-07539-6
Smith N, Leiserowitz A (2012) The rise of global warming skepticism: exploring affective image associations in the United States over time. Risk Anal 32(6):1021–1032. https://doi.org/10.1111/j.1539-6924.2012.01801.x
Sousa-Silva R, Verbist B, Lomba Â, Valent P, Suškevičs M, Picard O, Hoogstra-Klein MA, Cosofret V-S, Bouriaud L, Ponette Q, Verheyen K, Muys B (2018) Adapting forest management to climate change in Europe: linking perceptions to adaptive responses. For Policy Econ 90:22–30. https://doi.org/10.1016/j.forpol.2018.01.004
Soucy A, de Urioste-Stone S, Rahimzadeh-Bajgiran P, Weiskittel A, McGreavy B (2020) Understanding characteristics of forest professionals and small woodlot owners for communicating climate change adaptation. Trees for People 2:100036. https://doi.org/10.1016/j.tfp.2020.100036
Soucy A, De Urioste-Stone S, Rahimzadeh-Bajgiran P, Weiskittel A (2021) Drivers of climate change risk perceptions among diverse forest stakeholders in Maine, USA. Soc Nat Resour. https://doi.org/10.1080/08941920.2021.1991066
Spence A, Poortinga W, Pidgeon N (2012) The psychological distance of climate change. Risk Anal 32(6):957–972. https://doi.org/10.1111/j.1539-6924.2011.01695.x
Statistisches Bundesamt (Destatis) (2019) GENESIS-Online Datenbank. https://www.statistikdaten.bayern.de/genesis/online/logon. Accessed 03 Mar 2019
Staupe-Delgado R (2019) Progress, traditions and future directions in research on disasters involving slow-onset hazards. Disaster Prev Manag 28(5):623–635. https://doi.org/10.1108/DPM-11-2018-0358
Statista (2023) Bevölkerungsdichte in Deutschland von 1991 bis 2021 (Einwohner je km^2). https://de.statista.com/statistik/daten/studie/440766/umfrage/bevoelkerungsdichte-in-deutschland/
Süddeutsche Zeitung (2018) Waldbrand im Nationalpark Berchtesgadener Land weitgehend gelöscht. https://www.sueddeutsche.de/bayern/nationalpark-berchtesgaden-waldbrand-1.4085522?logout=true. Accessed 25 Mar 2022
Süddeutsche Zeitung (2023) Wie wird der Wald weiblicher? 30.09./01.10.2023, Nr. 226, page R9. https://www.sueddeutsche.de/muenchen/wolfratshausen/wald-frauen-gleichberechtigung-bad-toelz-wolfratshausen-1.6193058. Accessed 10 Oct 2023
Sundblad E-L, Biel A, Gärling T (2007) Cognitive and affective risk judgments related to climate change. J Environ Psychol 27:97–106. https://doi.org/10.1016/j.jenvp.2007.01.003
SurveyMonkey (2023) How to use a Top 2 Box score in your survey analysis. https://www.surveymonkey.com/mp/top-2-box-scores/
Taylor A, Bruine de Bruin W, Dessai S (2014) Climate change beliefs and perceptions of weather-related changes in the United Kingdom. Risk Anal 34(11):1995–2004. https://doi.org/10.1111/risa.12234
Thorn S, Bässler C, Svoboda M, Müller J (2017) Effects of natural disturbances and salvage logging on biodiversity: lessons from the Bohemian Forest. For Ecol Manag 388:113–119. https://doi.org/10.1016/j.foreco.2016.06.006
Thorn S, Müller J, Leverkus AB (2019) Preventing European forest diebacks. Science 365(6460):1388. https://doi.org/10.1126/science.aaz3476
Triebenbacher C, Lobinger G (2020) 2019: Borkenkäferdichte auf sehr hohem Niveau. Kühler Mai 2019 brachte keine Entspannung bei den Fichtenborkenkäfern. LWF Aktuell 124:42–45
Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A (2003) A framework for vulnerability analysis in sustainability science. Proc Natl Acad Sci USA 100(14):8074–8079. https://doi.org/10.1073/pnas.1231335100
Urquhart J, Potter C, Barnett J, Fellenor J, Mumford J, Quine CP, Bayliss H (2017) Awareness, concern and willingness to adopt biosecure behaviours: public perceptions of invasive tree pests and pathogens in the UK. Biol Invasions 19(9):2567–2582. https://doi.org/10.1007/s10530-017-1467-4
Van der Linden S (2015) The social-psychological determinants of climate change risk perceptions: towards a comprehensive model. J Environ Psychol 41:112–124. https://doi.org/10.1016/j.jenvp.2014.11.012
Viviroli D, Kummu M, Meybeck M, Kallio M, Wada Y (2020) Increasing dependence of lowland populations on mountain water resources. Nat Sustain 3:917–928. https://doi.org/10.1038/s41893-020-0559-9
Vulturius G, André K, Swartling AG, Brown C, Rounsevell M (2020) Successes and shortcomings of climate change communication: insights from a longitudinal analysis of Swedish Forest owners. J Environ Plan Manag 63(7):177–1195. https://doi.org/10.1080/09640568.2019.1646228
Walentowski H, Kopp D (2006) Leitlinien für eine gesamtdeutsche ökologische Klassifikation der Wald-Naturräume. Arch Nat Schutz Landsch Forsch 45:135–149
Wang C, Geng L, Rodriguez-Casallas JD (2022) How and when higher climate change risk perception promotes less climate change inaction. J Clean Prod 321:128952. https://doi.org/10.1016/j.jclepro.2021.128952
Weber EU (2010) What shapes perceptions of climate change? Clim Change 1(3):332–342. https://doi.org/10.1002/wcc.41
Whitmarsh L (2011) Scepticism and uncertainty about climate change: dimensions, determinants and change over time. Glob Environ Change 21(2):690–700. https://doi.org/10.1016/j.gloenvcha.2011.01.016
Witte K, Allen M (2000) A meta-analysis of fear appeals: implications for effective public health campaigns. Health Educ Behav 27(5):591–615. https://doi.org/10.1177/109019810002700506
World Meteorological Organization (WMO) (2019) The global climate in 2015–2019. Genf
Yousefpour R, Hanewinkel M (2016) Climate change and decision-making under uncertainty. Curr For Rep 2(2):143–149. https://doi.org/10.1007/s40725-016-0035-y

Yousefpour R, Augustynczik ALD, Hanewinkel M (2017) Pertinence of reactive, active, and robust adaptation strategies in forest management under climate change. Ann For Sci 74:40. https://doi.org/10.1007/s13595-017-0640-3