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ORIGINAL PAPER

How is adaptation to climate change reflected in current practice of forest management and conservation? A case study from Germany

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Abstract Climate change is expected to challenge forest management and nature conservation in forests. Besides forest species, strategies and references for management and conservation will be affected. In this paper, we qualitatively analysed whether forest conservation and management practice have already adapted to the impacts of climate change and to what extent those practices reflect the adaptation strategies dealt with in international peer-reviewed literature. To this end, we conducted thirteen in-depth interviews with forest practitioners (forest officers/forest district officers) in four regions in Germany. The interview regions were selected to represent the variation in tree species composition, forest ownership regimes and vulnerability to climate change. Although interviewees claimed to take climate change and adaptation strategies into account, in practice such strategies have as yet only occasionally been implemented. Our results suggest that strategies for adapting forest management to climate change are just in the early stages of development or supplement existing strategies relating to general risk reduction or nature-orientated forest management. The extent to which climate change adaptation strategies have influenced overall management varies. This variation and the lack of specific strategies also reflect the existing uncertainties about future changes in climate and about the capacity of forest ecosystems to adapt. We conclude that, in the face of climate change, forest management will have a major influence on future biodiversity composition of forest ecosystems. Hence, a framework for conservation in forests providing recommendations which also take into account the consequences of climate change needs to be developed.

Keywords Climate change · Biodiversity · Adaptive management · Forest conservation · Forest management · Europe

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Introduction

Forest management and conservation are expected to be considerably influenced by climate change. Altered climatic conditions will affect species distribution and local species composition (Huntley 1991; Hansen et al. 2001; Millar et al. 2007). References used for evaluating the conservation significance of forests, have to date been based predominantly on aspects of state and time, for example, the “nativeness” or “naturalness” of a forest area. Such references will be challenged by rapidly changing climatic conditions or may even lose their relevance (Perera et al. 2006). Accordingly, efforts to maintain a specific species composition or habitat may be questioned and some conservation objectives will shift (cf. Buse et al., this issue) or become obsolete (Huntley 1991; McCarty 2001). Adaptive responses, particularly of immobile species such as forest plants, are likely to lag behind the projected high rates of climate change (Hansen et al. 2001; Honnay et al. 2002). Moreover, species migration to new habitat is inhibited by human induced barriers such as fragmented and intensively managed landscapes (Davis and Shaw 2001; Bertin 2008). In forestry, problems will arise due to a shift in the bioclimatic envelopes of tree species, leading to the regional maladaptation of some tree species, e.g. *Picea abies* in several regions of Germany (Kölling et al. 2009). In commercial forests, regional increases in forest disturbances, such as drought, forest fires, pests or storm events, may cause damages and reduce species productivity (Dale et al. 2001; Kirilenko and Sedjo 2007; Hemery 2008).

Within the last decade, climate change impacts and possible adaptation strategies in forests have been a prevalent issue in scientific papers. Strategies are sometimes differentiated by the degree of human influence, for example into conservation of forest structures, as well as active and passive adaptation (Bolte et al. 2009b), or else into non-intervention measures, planned adaptation and reactive adaptation (Bernier and Schoene 2009). Recently, an adaptive forest management approach has been recommended, which is characterised by continual evaluation and, if necessary, adjustment of management objectives (Lasch et al. 2002; Rigling et al. 2008; Bolte et al. 2009b; Lawler et al. 2010). Moreover, forest ecosystems’ resilience in terms of climate change adaptation is stressed (Millar et al. 2007; Jump et al. 2010; Chmura et al. 2011). However, strategies for adapting forest or biodiversity management to climate change are often in the early stages of development, and recommendations for forest practice still lack specificity (Heller and Zavaleta 2009). Even though forest management is directly confronted with climate change, there have been few publications containing knowledge on current forest and conservation management practice in light of climate change. Ogden and Innes (2009) tried to identify local adaptation options by consulting forest practitioners. Wesche et al. (2006) observed that knowledge about climate change impacts had not yet led to an adjustment of management practice in protected areas in England. However, interview studies on climate change induced changes in management have mostly addressed the scientific or administrative sector.

The overall objective of this study was to analyse whether impacts and regional observations of climate change as well as scientific insights have already led to adaptation measures in forest practice. We consider first and foremost conservation objectives and measures which can be integrated into forest management but also include, to some extent, protected forest areas.

In detail, we aim to address the following research questions:

(i) To what extent does current forestry practice reflect the adaptation strategies discussed in international peer-reviewed literature?
(ii) Which adaptation strategies are planned for, and which are already implemented in current forest management and conservation practice?

(iii) What are the underlying motivations for planning or implementing these strategies?

Methods and materials

Study design and regions

We conducted a qualitative study, comprising semi-structured interviews with 13 forest practitioners in four regions of Germany in summer 2010. We followed a case study approach in order to investigate individual practices of dealing with climate change impacts. The study has the character of a pilot study which can serve as a basis for future interview studies, which might include a larger number of interviewees as well as additional regions. The interview regions for this study were selected with reference to the variation in tree species composition, forest ownership regimes and assessed regional vulnerabilities to climate change. They comprised the Swabian Alb, the Westerwald, Central Franconia and Lower Lusatia (Fig. 1). Vulnerability to climate change was mainly assessed on the basis of expected changes in mean temperature, water availability and species composition (Zebisch et al. 2005) and varied from 'moderate' (Swabian Alb, Westerwald, and Central Franconia) to 'highly vulnerable' (Lower Lusatia). Table 1 provides an overview of each of the study regions. In two regions, areas have been designated as UNESCO biosphere reserves, namely the Spreewald in Lower Lusatia (since 1991) and a large part of the Swabian Alb (since 2008). In these regions, local recreation also plays an important role as they are situated in the catchments of the urban agglomerations of Berlin and Stuttgart respectively.

Interview design and analysis

Interviewees from each region were selected using a multilevel approach (experts in the particular region were asked for recommendations for suitable interviewees).

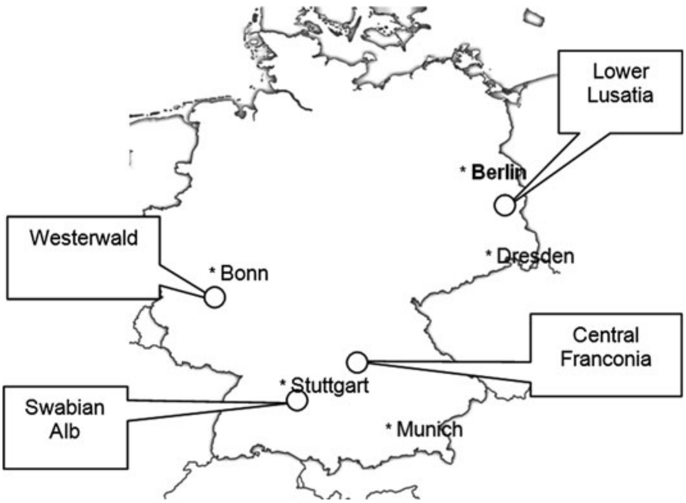

Fig. 1 Location of the interview regions in Germany (rough delineation)

Table 1 Interview regions

Region	Location	Geology and soils	Main tree species	Forest ownership regimes	Assessed vulner-ability
Central Franconia	South-east Germany	Keuper Mountain Sabulous nutrient-poor sites alternate with more loamey, clayey soils; sometimes fens; aeolian sands in river basin	*Picea abies; Pinus sylvestris* (*Fagus sylvatica*)	Large private Small private/ municipal State	Moderate
Lower Lusatia	North-east Germany	Glacial terrain. Groundwater-affected/waterlogged, nutrient-poor sites; ±nutrient-poor, sandy soils; periodically flooded soils (Spreewald)	*P. sylvestris* (*Quercus petraea; Q. robur; Alnus glutinosa; Fraxinus excelsior*)	Mid-sized private Federal State	High
Swabian Alb	South-west Germany	White Jurassic, Brown Jurassic. ±Thick clayey/loamy soils (plane areas); shallow soils where depletion/erosion occurred; humous, skeletal soils with scree material or sandy surface (slopes)	*F. sylvatica* (*P. abies; Abies alba; Acer pseudoplatanus; F. excelsior*)	Large private Municipal State	Moderate
Westerwald	West-Germany	Devonian Slate Mountain (slate, fine-grained sandstones, quartzite). Base-rich coarse clayey or clayey soils; slack water soils; sporadically acidic, nutrient-poor mineral soils	*F. sylvatica; P. abies* (*Q. spp.; A. pseudoplatanus; F. excelsior*)	Large private Municipal State	Moderate

Geology and important soils of the particular region compiled according to Gauer and Aldinger (2005). Tree species represent the main tree species of the particular region at present. Municipal forests were represented by consulting state forest officers. Vulnerability was assessed according to Zebisch et al. (2005)

In each region, representatives of between two and four forest enterprises of different forest ownership regimes (public or private) were interviewed. Overall, six interviewees represented public forests and five represented private forests of large and medium size. Federal forest, which was present in one region, was represented in one interview (Table 1). We conducted semi-structured, oral interviews based on a guideline (Bryman 2008). Interview questions were developed based on two literature reviews; one on climate change impacts on forest ecosystems (Milad et al. 2011), and the other on adaptation of forest management and conservation (Milad et al. in press). The first section of the guideline was aimed at identifying reasons for adopting adaptation actions and considered the interviewees' perception and observation of climate change impacts. The second section referred to planned and already implemented adaptation strategies (cf. Table 2). Interviews were predominantly conducted face-to-face with the exception of two which, for logistical reasons, were conducted by phone. All interviews were taped and transcribed. To analyse the interview results, we applied a qualitative content analysis approach based on Mayring (2010). This incorporated the technique of structuring interview material with regard to content (Mayring 2010). The statements made in the interviews were coded (Table 3) (Bryman 2008; Mayring 2010) and contrasted with conclusions drawn in current peer-reviewed literature on climate change and forest ecosystems. We therefore included papers from the literature review mentioned above (Milad et al. 2011), but complemented these with papers from the year 1999 onwards. The adaptation of temperate forests to climate change was emphasised using ISI Web of Science. The main structure of the results corresponds with the codes applied. More specifically, we grouped the assortment of codes into sub-categories of adaptation strategies relating to (a) tree species composition, (b) regeneration and natural succession, (c) the protection of species and habitats, and (d) conservation concepts and references. In each sub-category, results from literature and interviews based on our three main research questions are presented. Interview results are further divided into adaptation measures and underlying motives. Adaptation measures are described in relation to the different regions and are thereby, where possible, summarised as statements from regions assessed to be of moderate vulnerability (Central Franconia, Swabian Alb, and Westerwald) and high vulnerability (Lower Lusatia).

Table 2 Interview questions concerned both forest management and conservation

Forest conservation	Forest management	Motivations
Influence of climate change on adaptation strategies referring to		
Protected species and habitats	Tree species; tree species composition	General internal objectives
Conservation objectives	Other silvicultural aspects (regeneration, selection, thinning, growing stocks, rotation periods, harvesting)	Reasons for strategies, importance of climate change in decision-making process
Conservation concepts, references		Role of uncertainty
Different levels of forest diversity	Genetic aspects	Sources of information
Natural processes and dynamics	Azonal, extrazonal sites, ecotones	
Protected areas	Deer population density	
Ecosystem services	(Potential) areas of conflict	

Further questions were focussed on the motivations for implementing or planning adaptation measures

Table 3 Codes applied in the content analysis (categories I–V; subcategories i–ii; *CC* climate change)

		i	ii
I	No specific adaptation measures		
II	Active adaptation measures	Diversity	Tree species diversity
			Structural diversity
			Habitat diversity
			Genetic diversity
		Tree species choice	Deciduous—coniferous tree species (in general)
			Native—non-native tree species (in general)
			Native tree species (primary; main economic)
			Valuable deciduous tree species with high requirements for warmth
			Pioneer tree species
			Non-native tree species
		Regeneration	Natural
			Artificial (Planting, sawing)
		Natural succession stages	
		Rotation periods	
		Thinning	
		Growing stock	
		Deer density	
		Soil- and water protective measures	
III	Nature conservation	Importance and implementation	
		Conflicts	
		Observed impacts of CC	
		Adaptation measures to CC	
IV	Conceptual aspects	Internal objectives	
		Significance of “orientation by nature”	
V	Background of measures	Implementation	Coping with uncertainties
			Difficulties
			Timeframe
		Motivation	CC is main reason
			CC is one reason among others
			CC is not a reason

Results

Tree species composition

According to peer-reviewed literature, mixed stands with a wide variety of tree species, provenances and structures are expected to reduce risks, increase flexibility and maintain forest ecosystem functionality (Bugmann 1999; Lindner 1999; Bodin and Wiman 2007; Hemery 2008). In addition to forest stand diversity, diversity at the landscape level may facilitate adaptation and buffer the impacts of climate change related disturbances such as insect outbreaks, forest fires or storms (Hemery 2008; Rigling et al. 2008).

Some authors point out that knowledge on the adaptive capacities of tree species is still limited (Brang et al. 2008; Bolte et al. 2009a). However, *P. abies* is considered to be particularly vulnerable to climate change and thus is expected to lose a significant part of its current range in Germany (Roloff and Grundmann 2008; Albrecht et al. 2009; Bolte et al. 2009a). In an interview study, *P. menziesii* is identified as gaining importance in forest management in Germany, however additional knowledge in relation to its responses to climate change is needed (Bolte et al. 2009a). If cultivation experience is lacking, alien species should be tested in terms of their appropriateness as well as of impacts on, and interactions with, the local environment (Hemery 2008; Roloff and Grundmann 2008; Bolte et al. 2009b). Several authors expect deciduous tree species to be less vulnerable to climate change than conifer species (Schelhaas et al. 2003; Rigling et al. 2008; Albrecht et al. 2009). Furthermore, it is assumed that, on a regional basis, deciduous tree species with an optimal range in warm, sub-Mediterranean climate or whose range is currently limited by cool temperatures and late frost (e.g., *Juglans regia*, *Castanea sativa* or *Sorbus* spp.,) will also gain importance for forest management, regardless of whether they are presently considered native or non-native (Lindner 1999; Hemery 2008; Roloff and Grundmann 2008).

According to our interviews, adaptation in forestry practice is mainly linked to tree species choice. Collectively, interviewees mixed, or planned to mix, tree species for the purpose of spreading climate change related risks (Table 4). The intended diversity of tree species mixture varied within the regions; whereas one interviewee aimed at "certain mixture proportions", others considered as many site-specific suitable tree species as possible. One interviewee stated that species mixture was particularly important at vulnerable sites.

In the regions assessed to be of moderate vulnerability (Central Franconia, the Swabian Alb and the Westerwald), *P. abies* accounts for notable proportions of the whole forest area and was considered to be particularly prone to climate change. In Central Franconia, interviewees representing public forests planned to convert at least half of the high risk stands of *P. abies* into stands of mixed deciduous species within coming decades, whereas in a private forest, stands of *P. abies* are to be maintained for at least one more generation. In the Westerwald, one practitioner reported the reduction of *P. abies* following severe storm events, whereas two practitioners of a public and a private forest noted that the proportion of *P. abies* had not yet been reduced. However, one of them intended to do so in the future for the benefit of *Abies alba*, *Pseudotsuga menziesii* and *Larix* spp. Where stands of *P. abies* were maintained, interviewees aimed at increasing stability through species mixture, an early establishment of the next generation or thinning measures. Several practitioners in each of the three regions planned an increase in *P. menziesii.* The extent to which *P. menziesii* was included differed both between regions and forest enterprises. In public forests of Central Franconia, it was intended that *P. menziesii* makes up a maximum

Table 4 Adaptation measures and assessments about tree species' vulnerability in view of climate change based on literature and the interview study (structured according to the four interview regions)

Category	Subject	Literature	Central Franconia	Swabian Alb	Westerwald	Lower Lusatia
Tree species	Species composition	Increase diversity; tree species mixture	Increase diversity; tree species mixture	Increase diversity; tree species mixture	Increase diversity; tree species mixture	Increase diversity; tree species mixture
	Valuable deciduous tree species	Gaining importance	Rather tolerant; gaining importance	Rather tolerant	Rather tolerant; single losses due to drought	Rather tolerant; gaining importance
	Picea abies	High vulnerability	High vulnerability; conversion maintenance	High vulnerability; conversion	High vulnerability; conversion; maintenance	
	Abies alba		Rather tolerant gaining importance	Rather tolerant gaining importance	Rather tolerant gaining importance	
	Pseudotsuga menziesii	Uncertainties; Research	Increase	Increase	Increase Uncertainties	
	Pinus sylvestris			Rather tolerant	Rather tolerant	Rather tolerant
	Fagus sylvatica		Rather tolerant	Rather tolerant; vulnerable to drought	Rather tolerant; vulnerable to drought	
	Quercus spp.		Rather tolerant	Rather tolerant	Rather tolerant	Rather tolerant; tolerance questioned
	"Exotic" tree species	Uncertainties; Research	Sporadically planted	Sporadically planted	Sporadically planted	Sporadically planted
Regeneration & succession	Natural regeneration	Increasing adaptation potential	Dominating	Dominating; increasing adaptation potential	Dominating	Limited experiences, future increase
	Artificial regeneration	Planting of additional species	Mainly planting of additional species	Mainly planting of additional species	Mainly planting of additional species	Sowing, planting
Regeneration & succession	Regeneration of vulnerable species		Initiate regeneration earlier	Initiate regeneration earlier	Initiate regeneration earlier	

Table 4 continued

Category	Subject	Literature	Central Franconia	Swabian Alb	Westerwald	Lower Lusatia
	Rotation periods	Reduction considered; reduction disapproved; extension	Reduction considered	Reduction considered; reduction disapproved	Reduction considered	
Protection of species & habitats	Specific adaptation		No specific measures	No specific measures	No specific measures	No specific measures
	Water balance					Restoration
	Habitat diversity	Increase habitat heterogeneity		Increase considered		
	Monitoring	Improve; essential base				Considered to be helpful
	Connectivity	Increase/Improve				
	Protected areas	Adaptation (e.g. size, locations, management)				
Conservation concepts	References	Reassessment	Partially questioned	Partially questioned	Partially questioned	Partially questioned
Coping with uncertainty		Increase diversity	Increase diversity	Increase diversity	Increase diversity	Increase diversity
		“No-regret-strategies”			“No-regret-strategies”	
			Await further developments		Await further developments	
		Adaptive management				

proportion of 3 % of the whole forest. In a private forest it has been planted in single mixture within the last decade. One respondent from the Swabian Alb stated that if site conditions were suitable, conifers would not be substituted by deciduous species, particularly given that the region was rich in deciduous stands. As such, he considered a distinct shift from *P. abies* to *P. menziesii*. Another interviewee from the Swabian Alb planted *P. menziesii* in small harvesting clearances in beech forests. In the Westerwald, one interviewee considered larger plantings of *P. menziesii* in order to prevent selective browsing, while a second respondent wanted to avoid significant alteration of forest structures through the plantation of *P. menziesii*, and a third interviewee was even more cautious and pointed at existing uncertainties associated with this tree species.

Regarding other main tree species, experiences and assessments differed. In Central Franconia, one interviewee considered that *A. alba F. Sylvatica* and *Quercus* spp. were gaining in importance for forest management, while in another forest enterprise, *A. alba* played a minor role. In the Swabian Alb, *A. alba*, *Pinus sylvestris* and *Fagus sylvatica* were thought to be generally tolerant towards climate change. However, one interviewee reported having observed growth decline in stands of *F. sylvatica* as a consequence of severe drought periods. In the Westerwald, *F. sylvatica* was expected to maintain its previous importance. In contrast, one interviewee linked the more frequent occurrence of red heartwood to an increase in heat periods. Several interviewees expected *Quercus petraea* and *Quercus robur* to benefit from climate change because of their high requirements for light and warmth. Due to their life traits, they were considered for the reforestation of open areas in the Westerwald. One respondent in Central Franconia suggested that *Quercus* spp. could be facilitated, whereas another interviewee from the same region perceived *Quercus* spp. to be less drought-tolerant than often reported; salvage cuttings due to drought induced damages had already been necessary. One practitioner of a private forest in the Westerwald had attempted the cultivation of *P. sylvestris* and had so far observed positive results.

Valuable deciduous tree species, such as *Acer* spp., *Fraxinus excelsior* or *P. avium*, were reported to be gaining importance. Also sporadical plantings of *Sorbus* spp., *C. sativa*, *R. pseudoacacia* or *J. regia* were reported for municipal and small private forests in Central Franconia. However, where rare *Sorbus*-species existed, they played only a secondary role in adaption. *Alnus glutinosa* was expected to be imperilled by an increase in drought periods which would limit appropriate sites in the future. One interviewee observed negative impacts of drought on ravine forests through a loss of *Acer pseudoplatanus* and *F. excelsior*.

In all three regions, more "exotic" tree species such as *Sequoia gigantea, Corylus colurna, Liriodendron tulipifera* or *Ginkgo biloba* were planted sporadically by way of trial. One practitioner of a private forest reported planting *Robinia pseudoacacia* on extremely dry and rocky sites for the purposes of soil and slope protection. He had not as yet observed invasive potential. Overall, the proportion of alien species was expected to be too small as yet to provoke conflicts between forest management and conservation objectives, however a further increase could lead to future conflicts.

In Lower Lusatia, interviewees assumed that *P. sylvestris* remained the dominant tree species within a mixture with deciduous species. One interviewee questioned the tolerance of *Quercus* spp. towards climate change. *Acer spp., F. excelsior* and *P. avium* were also expected to gain in importance on nutrient-rich sites with adequate water supplies. In a private forest, attempts to plant *P. menziesii* had failed due to drought. As a consequence, the owner intensified the planting of *Quercus rubra*. For the public forest in Lower Lusatia a maximum of 5 % of alien tree species in general were defined. While interviewees representing public forests consciously integrated pioneer species, one private forest practitioner stated that they merely tolerated *Betula* spp. Another respondent reported failure of pioneer forests as a result of severe drought.

Analysing the motives for reassessing tree species choice and increasing species diversity, the reduction of risks related to tree species growing on inappropriate sites were often noted as being crucial. For instance, the conversion of pure *P. abies* stands was conducted in response to their high susceptibility to storms, pests and diseases. However, one interviewee expected that climate change would lead to greater risk awareness regarding specific tree species. In Central Franconia, one respondent attributed the considerable reduction in proportions of *P. abies* to climate change. He further assumed that though objectives such as increasing tree species diversity had previously existed, climate change would lead to a more diverse mixture of species. In some regions, reassessment of tree species directly followed disturbances or combinations of multiple disturbance events. An increase in pioneer species was sometimes connected to more frequent disturbances; e.g. *Betula* spp. were adopted due to a temporary protection for seedlings susceptible to conditions of open areas. One interviewee representing a medium-sized private forest reported that he mainly selected tree species based on advice from the state forest consultancy.

Regeneration and succession stages

Peer-reviewed literature illustrates that high initial numbers of seedlings together with selective pressure will allow for the survival of the best adapted individuals (Roloff and Grundmann 2008). However, regeneration of vulnerable tree species such as *P. abies*, faces a higher risk of failure (Lindner 1999). Chmura et al. (2011) suppose that warmer temperatures in spring could be positive for germination and recruitment, while warmer autumn temperatures might increase winter mortality due to early germination. Increasing drought will probably negatively affect regeneration stages (Chmura et al. 2011). In cases where natural regeneration does not succeed as a consequence of climate change, additional plantings may be useful (Nitschke and Innes 2008b). Planting may also serve to increase species diversity (Lindner 1999; Brang et al. 2008). Smulders et al. (2009) further propose transferring seedlings both from unsuitable to assumedly more suitable sites and from more adapted populations to small, isolated or less adapted populations.

In terms of late succession stages, reduced rotation periods are sometimes expected to decrease the risk of abiotic damages, particularly the consequences of drought or storm events (Maracchi et al. 2005; Albrecht et al. 2009). Furthermore, management responses to disturbances or the conversion of vulnerable conifer stands may be advanced (Lindner 1999; Noss 2001). However, Noss (2001) advises against reduced rotation periods on the basis that critical soil nutrients may be depleted. Some authors even advocate a further extension of rotation periods in order to maximise carbon storage for economic and ecological reasons (Brett 2008; Evans and Perschel 2009; Burgess et al. 2010).

Our interviews showed that in Central Franconia, the Swabian Alb and the Westerwald, natural regeneration was dominant in comparison to artificial regeneration (planting, sowing). When asked about the meaning of natural succession stages, interviewees often first thought of allowing for forest succession in partial areas, which was a common measure in forest management. Several interviewees claimed that they allow for an increase in structural forest diversity, but this mostly in clearances resulting from forest disturbances. In Central Franconia, one interviewee, who consulted small-scale private forest owners, reported that proportions of natural and artificial regeneration were almost balanced and depended on the particular forest owner. In the Swabian Alb, one interviewee pointed to counterproductive effects of artificial regeneration in light of climate change as it may lead to single mixtures or monocultures. Regarding the natural regeneration of *P. abies*, several interviewees from Central Franconia and the Westerwald stated that they would tolerate its natural regeneration or await its further development. In both regions, practitioners from public and private forests intended to initiate regeneration of *P. abies* earlier than in the past; which meant at a stand age from 40 to 60 years. Where additional tree species were established, planting in small groups was common.

In all three regions, interviewees took a reduction of rotation periods into account. In Central Franconia and the Westerwald, shorter rotation periods were primarily considered for *P. abies*, however, in each case one interviewee stated that an early achievement of target diameters was intended for all tree species. While one interviewee from the Swabian Alb argued against shorter rotation periods, another one took them into account for *P. abies*, *F. sylvatica* or *Quercus* spp., however he had not yet drawn a final conclusion.

In Lower Lusatia, one respondent reported little experience and missing references regarding natural regeneration as sowing was common. However, he planned to increase the proportion of natural regeneration in future. No changes were intended in regard to rotation periods.

Amongst the motives behind the preference for natural regeneration were economic and ecological reasons or the principles of nature-orientated forest management, the latter of which include the prioritisation of natural regeneration and are further specified by the respective state forest administration. Climate change also had an influence to some extent. For example, interviewees from the Swabian Alb pointed to the high genetic diversity of natural regeneration, expecting it to lead to an establishment of the most adapted individuals and enable tree species to survive temperature changes. Devaluation due to drought-induced damages or age-related risks (red heartwood, heart rot) was often cited as a reason for the reduction of rotation periods. In one case, the reduction of rotation periods was explicitly rejected due to detrimental ecological effects.

Protection of species and habitats

In peer-reviewed literature, connectivity, both between protected areas and across the entire forest landscape, is expected to facilitate adaptation to climate change (Smulders et al. 2009). Further, positive effects of habitat heterogeneity on species adaptation are reported. Gillson and Willis (2004) suggest that species movement and hence the adaptation of species' local distributions to altered site conditions should be facilitated. Small-scale heterogeneity, such as variation in edaphic conditions, can provide refugial areas where species are able to survive adverse conditions (Noss 2001; Nitschke and Innes 2006, 2008a).

Monitoring facilitates increasing knowledge and understanding of ecosystem responses to altered conditions (Aber et al. 2001; Hossell et al. 2003; Normand et al. 2007; Bässler et al. 2010), and assists in the identification of species at risk (Noss 2001). Jump et al. (2010) highlight the necessity for high resolution monitoring data, particularly to identify changes at species' southern distribution edges. Bässler et al. (2010) recommend monitoring the occurrence of temperature sensitive indicator species. Numerous authors emphasise the value of long-term monitoring as a basis for adaptive management (Scott and Lemieux 2005; Coenen et al. 2008; Lawler et al. 2010; Burgess et al. 2010). In several papers, protected areas and the European Union's network of coherent protected areas, Natura 2000, are discussed with reference to climate change (Normand et al. 2007; Hannah

2008; Vos et al. 2008). Forest protected areas should be adapted to climate change, for example by increasing the area protected (Hossell et al. 2003; Hannah et al. 2007; Hannah 2008; Mawdsley et al. 2009). New protected areas should be established in order to increase habitat connectivity (Gillson and Willis 2004; Hannah 2008; Vos et al. 2008). Mawdsley et al. (2009) suggest creating new protected areas along elevational gradients to allow species to adapt to their regional distributions. Hannah (2008) refers to protected areas that are more mobile in space and time (e.g. rotating closures), which might facilitate adaptation in a period of transformation and rapid change. In existing protected areas, management should be adapted (Welch 2008; Mawdsley et al. 2009). This entails not only increased flexibility but also the creation of knowledge and enhanced professional competence (Scott and Lemieux 2005).

Interviewees did not identify any specific measures for adapting the protection of forest species and habitats to climate change. However, one interviewee from the Swabian Alb stated that forest management could provide high habitat diversity, including cooler microclimatic areas which could serve as climate refugia.

Assessments of the influences of climate change on conservation in forests did not considerably differ between the study regions. Several interviewees assumed that climate change will lead to more pronounced fluctuations in water balance and increasing drought, thereby altering species composition or impeding conservation measures such as the restoration of water bodies or peat lands. Some interviewees expected the alteration of species composition and diversity due to climate change, e.g. in protected areas of the habitat network Natura 2000. Overall, practitioners expected that species adapted to cool-humid conditions would be negatively affected, and conversely, that xerothermal vegetation would benefit. One practitioner expected succession progress to slow down on dry sites. For the most part, interviewees considered an increase in disturbances to be beneficial for biodiversity conservation objectives in forests. They could increase mortality or reduce growth and thus lead to a disturbance-induced mosaic of open and denser areas of different size or create new forest edges. A greater amount of dead wood could further provide habitat for dead wood dwelling species. However, one interviewee in the Westerwald feared that strong wind events in summer could cause severe damage in old growth stands, particularly affecting habitat trees or standing dead wood.

In Lower Lusatia, interviewees referred to measures for restoring the landscape water balance or reversing the negative impacts of former amelioration. In the same region, drought-induced problems in implementing compensation measures, such as reforesting former agricultural cropland, were reported by one interviewee who considered enrichment of existing forest stands through planting of deciduous tree species as an alternative. Monitoring changes was considered to be a useful basis for climate change adapted management plans; however, no practicable strategies existed.

Analysis revealed that none of the motives for measures aimed at the protection of habitats and species were solely related to climate change. Some measures resulted from a state-wide strategy, e.g. the restoration of the landscape water balance in Lower Lusatia was initiated by the federal environmental agency. On the one hand, these measures were associated with climate change adaptation as they are thought to increase forest ecosystem resilience. On the other hand, they were linked to a general improvement of water supply.

Conservation concepts and references

In peer-reviewed literature, several authors call for reassessment of native species classifications in light of changing site conditions and species movements (Broadmeadow et al. 2005; Millar et al. 2007; Bertin 2008). Scott and Lemieux (2005) refer to the difficulties in defining what is natural vegetation or a natural ecosystem. The current trend towards mixed deciduous forests and the integration of natural processes into forest management, often subsumed as nature-orientated forest management, is generally assessed as contributing positively to climate change adaptation (Schelhaas et al. 2003; Hemery 2008; Bollmann et al. 2009). However, Brang et al. (2008) point out that common forest management approaches alone will not suffice as site conditions and species' conformity to the site will change. Integration of natural processes may further involve accepting natural disturbances to a certain degree (Schelhaas et al. 2003). The careful observation of ecosystems' responses to climate change is expected to increase flexibility in terms of adaptive management (Hemery 2008).

Most forest practitioners intended to balance forest management and conservation objectives. Several respondents explicitly argued for an integrative conservation strategy. Some interviewees questioned current references for conservation measures such as "native tree species composition" or "natural vegetation" and called for a critical discussion. The relevance of naturalness as a reference for forest management varied both between regions and forest enterprises. In Central Franconia, two interviewees representing a public and a private forest disagreed with maintaining a specific ecosystem state opposed to natural dynamics by means of intensive measures. In the Swabian Alb, one respondent of a private forest assumed that the significance of naturalness would vary between the executive forest rangers. One interviewee of a public forest asserted that orientation towards nature was of high importance. He claimed that conservation objectives in his forest area were not to be compromised by economic objectives but added that objectives which could cause competitive situations, such as maintaining dead wood, including alien species or reducing rotation periods, were to some extent pursued over spatially distinct areas. In the Westerwald, several interviewees considered tree species belonging to the respective natural forest community to be an important foundation for future forest management.

In Lower Lusatia, one practitioner claimed that he did not primarily aim towards the achievement of naturalness, but rather worked by trial and error and observed which species grow well.

Motives mentioned by interviewees for a reassessment of concepts and references in light of climate change included rapidly changing site conditions as well as a high anthropogenic imprint on forest sites. One interviewee representing a private forest enterprise declared that, despite being close to a natural state, establishing only forest communities dominated by *F. sylvatica* was not an operative objective due to economic reasons.

Coping with uncertainties

Where high uncertainties preclude the favouring of specific adaptation measures, spreading risks by increasing different levels of forest diversity is recommended in peer-reviewed literature (Broadmeadow et al. 2005; Bodin and Wiman 2007; Rigling et al. 2008). For instance, risks can be reduced through a mixture of species and provenances (Bernier and Schoene 2009; Bolte et al. 2009b; Evans and Perschel 2009). Authors also propose the diversification of forest management, which requires combining a number of different management options (Bodin and Wiman 2007) and adaptation strategies (Smulders et al. 2009). Several authors suggest implementing "no-regret-strategies" which are thought to be beneficial under various future climate conditions (Lawler et al. 2010; Ogden and Innes

2009). They include measures such as increasing diversity (species, structures) and connectivity, avoiding soil disturbances or advancing knowledge and research. Bernier and Schoene (2009) point out that the uncertainties related to climate change will be much higher than those which have thus far characterised forest management. During recent years, adaptive management has been promoted as a successful means of managing forest ecosystems despite high uncertainties (Welch 2008; Lawler et al. 2010). To identify initial practicable adaptation measures, information about species vulnerabilities and adaptive capacities of forest ecosystems is required (Bolte et al. 2009b; Chmura et al. 2011), and existing uncertainties need to be assessed (Millar et al. 2007; Bernier and Schoene 2009). Scenario-setting and monitoring are therefore essential elements of adaptive management (Coenen et al. 2008; Bernier and Schoene 2009; Lawler et al. 2010).

Uncertainties referred to by the interviewees were often directly linked to climate change and future climate development. In light of these uncertainties, some of the interviewees from Central Franconia, the Swabian Alb and the Westerwald demonstrated a certain restraint in their preference for a moderate adaptation approach. For example, one interviewee of a public forest in the Westerwald reported his preference for awaiting further developments and then reacting as opposed to acting pre-emptively.

Another respondent (private forest) mentioned strategies which are advantageous regardless of exactly how climate will change, e.g. increasing species diversity, including natural dynamics ("biological automation"), or cautious, soil- and water-protective forest management. Other respondents took the approach of spreading risks via increasing forest diversity and stability. In Lower Lusatia, a manager of a private forest stated that uncertainty had not yet led to precise strategies and therefore that tree species choice was not yet orientated towards future conditions.

Over all regions, several interviewees had found it necessary to undertake more specific research to minimise existing uncertainties, while others called for applying already existing knowledge. Interviewees used various sources of information about climate change and adaptation, such as professional journals, mass media and specific training courses. Direct scientific information, e.g. from scientific journals or via cooperation with universities, was used to differing degrees. However, available scientific information was sometimes considered too abstract or scattered and interviewees suggested that it should be presented in a more comprehensible manner.

While most of the practitioners were more or less convinced that climate change will occur or is already occurring and saw a need to develop adaptation measures, several interviewees considered that climate change has not yet been reliably proven. They stated that even though some indicators support the existence of climate change, other signals pointed to a less dramatic development. Some interviewees considered intense forest disturbances to be indicators of climate change, whereas others questioned this correlation or pointed to short periods of observation. Where forest disturbances had led to significant damages, practitioners felt forced to take action.

Discussion

Adaptation of forest management

Even though interviewees in our study claimed to take climate change into account, adaptation strategies have, until now, only occasionally been implemented in forest management and even less so in forest conservation. In regions with notable influence of disturbances, adaptation planning was already in progress, whereas in other regions, interviewees had only taken climate change into account quite recently. The influence of disturbances varied locally with corresponding differences in adaptation pressure. For example in the Westerwald, differences between the studied forest enterprises existed with regards to the effects of storms or drought. In addition to sites and exposition, existing tree species composition was crucial. For instance, where *P. abies* made up a large proportion of the stand, damages were usually more severe. Reconsidering tree species choice and increasing forest diversity were the most common management responses suggested both in the interview results and in literature (cf. Table 4). Increasing tree species diversity is considered as an insurance approach which spreads climate-related risks (Hemery 2008). Nevertheless, changes in species composition may both positively and negatively influence habitat diversity and quality for associated species (cf. Katona et al., this issue).

While the interviewees generally alluded to specific tree species and their silvicultural application in a changing climate, statements in the literature were less often specific to tree species. In forest management, practical knowledge gained through experience and personal observation plays a considerable role and may lead to planting of tree species in addition to those recommended by researchers. Additional information, e.g. from consultancy, training courses or (national) professional journals, may also have a strong influence on management decisions. In the context of a research initiative to tackle forest decline, Pregernig (2000) found that training courses had the most distinct effects on the behaviour of forest practitioners in Austria in comparison to other information sources; direct scientific information only played a role in medium- and large-scale forest enterprises.

Decisions in practical forest management are strongly motivated by economic requirements. In several of the forest enterprises interviewed, economic motives led to the maintenance of *P. abies* stands or the substitution by other conifers as opposed to deciduous species. Additionally, sporadic plantings of *Sorbus* spp. by private or municipal forest owners in some of the interview regions were more economical motivated than by climate change. Both interviewees and authors expected deciduous tree species with high requirements for warmth as well as pioneer species to gain in importance (Lindner 1999; Nitschke and Innes 2006; Hemery 2008; Roloff and Grundmann 2008). However, in those of our interview regions where these species could potentially exist, they formed only a minor proportion of the entire stand. In both literature and interviews, natural regeneration was expected to facilitate adaptation to climate change. However, whereas the use of provenances from more southern regions or lower altitudes was repeatedly considered in literature (Bolte et al. 2009b; Schiessl et al. 2010) it has not yet been an important strategy in the interview regions. A reasonable cause for this discrepancy is that cultivation experiences are still missing and precise species and provenance recommendations are still to be adapted to climate change (Schüler et al., this issue). Moreover, scientific conclusions regarding the vulnerability of specific tree species in a changing climate may differ (Milad et al. 2011), thereby increasing uncertainty on the part of forest managers.

Our interviews further reveal that some measures reflect both adaptation to climate change and strategies independent of climate change. Projections on climate change predominantly lead to an accelerated and more consequent implementation of previous strategies. Examples are the conversion of inappropriate and hence unstable stands of *P. abies* and *P. sylvestris* into more stable, mixed stands; or the earlier achievement of target diameters through altered thinning regimes and reduced rotation periods. The main intention of these strategies is to reduce the risks of devaluation resulting from climate change induced disturbances but also from known fungal diseases. Consequently, in the context of climate change, reduced rotation periods also allow for the maintenance of vulnerable tree species such as *P. abies*, at least in the short-term. In contrast to some peer-reviewed papers, extending rotation periods in order to maximise carbon storage was not considered by the interviewees. Negative ecological effects of reduced rotation periods are a relevant subject of discussions on forestry and conservation. Forestry already reduces the natural lifespan of trees through timber production, thereby excluding decay stages (Nilsson 2009). Thus, habitat diversity is reduced. In the long-term, any kind of wood use will lead to a considerable reduction of groups that specialise on dead wood structures (Müller et al. 2007).

Adaptation of conservation strategies

In the interviews, implications of climate change for nature conservation were often assumed rather than observed. The forest practitioners generally noted that they did not have specific strategies for adapting conservation in forests to climate change. Nevertheless, many interviewees reported that nature conservation was of high importance for forest management. This was particularly the case where protected areas made up a comparably large proportion of the forest enterprise, such as in the biosphere reserves (Swabian Alb and Lower Lusatia), but also where there was a long tradition of nature-orientated forest management or where forests were certified. Again, different levels of diversity were thought to be of particular significance for adapting to climate change, both in literature and in the interview results. However, increasing connectivity to allow species to adapt their ranges to climate change, a measure commonly recommended in literature (Noss 2001; Vos et al. 2008), was not mentioned by the interviewees. Different spatial levels of consideration are one likely reason for this: whereas forest practitioners generally focus on the forest enterprise or even forest stands, authors of scientific literature increasingly emphasise the importance of large-scale or landscape levels (Rigling et al. 2008; Mawdsley et al. 2009). Furthermore, forest management is not dependent on natural migration of tree species since they can also be relocated anthropogenically. Thus, measures to assist natural migration of forest species are probably only taken into consideration if managers decide to let forest ecosystems adapt independently.

The planning and implementation of monitoring measures may not have been adequately reflected in our interviews given that the responsibility for these activities rests with other authorities. Given altered precipitation regimes, measures related to the water balance of forest landscapes are likely to gain in importance. Innovative cooperation between different disciplines of resource management, such as forestry and water management, but also agriculture or conservation can be of particular value in relation to ecosystem resilience (Frommer 2011).

Several practitioners expected that references which are based on constant site conditions, a specific time period or state of naturalness will be particularly challenged by climate change. Amongst other reasons, this perception may well result from general practical experiences of a dynamic nature. Additionally, a static definition of what is natural constrains the cultivation of additional tree species. Several interviewees argued explicitly for an integrative conservation approach (in contrast to a segregative approach). It appeared as though some of them perceived segregative and integrative conservation approaches as being mutually exclusive. Thus, segregative approaches may have been rejected by interviewees who associated them with further management constraints.

Incorporating uncertainties into management

Our results reveal that uncertainties in the context of climate change were firstly related to future climate development and secondly to adaptation of forest ecosystems and management. For instance, some interviewees attributed current disturbances to climate change whereas others were sceptical. In part, these uncertainties are caused by the limited timeframe of observation which does not allow for clear assumptions, for instance in relation to storm frequency (Albrecht et al. 2009). Sometimes, interviewees had only been working for a few years in the region in question and thus could not draw personal conclusions regarding climate or disturbance trends. Accordingly, diverse approaches for handling climate change related uncertainties existed, including individual aspects. Some practitioners chose "no-regret" objectives and measures or intended to spread climate change related risks as was shown in the context of tree species selection. Others indicated their intention to await further developments before taking action. In those (partial) regions, where interviewees demonstrated some restraint, disturbances either had not had a major influence to date or interviewees were not convinced that climate change will occur with the predicted magnitude. Other respondents intended to react cautiously and take a stepwise approach towards improving adaptation strategies, which is also mentioned as "learn-as-you-go" strategy in scientific literature (Millar et al. 2007). This can form part of an adaptive management concept proceeding with periodic evaluation and adjustment of strategies and measures (Bodin and Wiman 2007; Brang et al. 2008; Bernier and Schoene 2009; Lawler et al. 2010). However, adaptive management involves the identification of management options, based on scenarios or models (Wintle and Lindenmayer 2008). As it is unlikely that uncertainties will be totally reduced in future (Gray 2011), knowledge gaps are to be explicitly integrated in management. Future scenarios can be developed through assessments of uncertainties and the main drivers of climate change. Subsequently, management options are analysed regarding their feasibility under different future climates. In this way, both "no-regret" and "no-gain" measures can be identified (Gray 2011). Occasionally, adaptive management may be constrained by limited experimental scope in relation to particular resources and, if effects are socially or legally intolerable, adaptive management will be inoperable (Gunderson 1999).

Some interviewees stated that uncertainty was aggravated by abstract scientific information. Regarding adaptation of forest conservation to climate change, information seems to be insufficient. The issue itself is highly complex, which might impede the identification of appropriate adaptation measures (Van Kerkhoff and Lebel 2006). Additionally, non-scientific sources of information on nature conservation in forests might appear inconsistent due to multiple stakeholders' interests (Perera et al. 2006), which increase complexity. These are recognized problems in scientific knowledge transfer which call for an improved dialogue between science and practice (Prendergast et al. 1999; Perera et al. 2006). However, more comprehensible, simplified representations of complex issues may bear the risk of inadequate assessments and practical measures (Van Kerkhoff and Lebel 2006; Jones and Preston 2011). Amongst others, the attitudes of forest practitioners towards adaptation are an important precondition for adaptation results (Frommer 2011). Gray (2011) supposes that existing climate change related uncertainties may deter decision-makers from implementing efficient management actions. Additionally, significant uncertainties may be used by decision-makers to justify a business as usual approach (Jones 2001). Given that deficits in motivation may considerably reduce adaptation results, bottom-up approaches, which include the relevant stakeholders, are vital (Frommer 2011).

Conclusions

The forest practitioners interviewed for this study are quite aware of possible implications of climate change as well as several opportunities for adapting forest management to climate change. Though practical adaptation strategies are still in the early stages of development, strategies discussed in peer-reviewed literature have been incorporated. However, this applies mainly for strategies related to forest production and less so to conservation. Further, in light of the considerable range of climate change related uncertainties, most of the adaptation measures are rather broad and aim at spreading risks by increasing forest diversity. Despite general trends in adaptation, different regional conditions and personal attitudes towards climate change or differing internal and external pressures in the forest enterprises lead to individual and thus diverse adaptation approaches. This may in turn enhance adaptive potentials on the landscape scale. However, this should not serve to justify business as usual approaches. Forest management and how it is implemented will be crucial for the future composition and biodiversity of forest ecosystems. Thus, long-term outcomes of adaptation strategies have to be kept in mind. This requires a repeated evaluation of strategies and measures to allow for their adjustment according to an adaptive management approach. Experiences of forest practitioners should be involved as they can build a valuable base for identifying initial measures. Scientific findings relating to adaptation measures need to be communicated in an adequate, comprehensible way. In order to factor forest conservation into adaptation strategies to a greater extent, a transparent forest conservation strategy is essential. Such a strategy requires the joint (re-)discussion of values and objectives of both forest conservation and management.

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