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# Strategies of Handling Risk and Uncertainty in Forest Management in Central Europe

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**Abstract** This paper deals with different levels on which the challenge of risks and uncertainty is addressed in forest planning—in theory and practice, with regard to the organization of forest management planning as well as in individual long-term decision making of practitioners. Therefore, it first shortly defines the most relevant terms and describes sources, types and categories as well as the basic modes of handling risks and uncertainty relevant for science and planning practice. In the second part, approaches to handle risk in forest management planning systems are described within the framework of the risk management process. The third part of the section deals with theoretical approaches to measure risk and uncertainty and introduces forest management planning models as well as standard economic risk models. The fourth summarizes empirical studies where individual and organizational decision making and planning processes in the face of risk and uncertainty are analysed and shows how challenges of complexity and uncertainty, as influenced by psychological as well as social factors, are handled in real forest management. The conclusions (part 5) point to the discrepancy between the theoretical and practical handling of uncertainty and risk.

**Keywords** Uncertainty · Forest management · Risk management process · Decision making

This article is part of the Topical Collection on *Forest Management*

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## Introduction

### Modern Risk Society and the Uncertainty

Within modern "risk society" [1], risks, uncertainties and non-knowledge in the face of global change have become pivotal not only in ongoing debates about ecological modernization [2], but also in the debates regarding global environment and development and the studies on global governance. In the face of "global change", characterized not only by climate change but also by the depletion of resources and energy supply and the endangerment of natural resources and biodiversity, the successful pursuit of changing and transforming the environment has resulted in a corresponding growth in uncertainty [3].

The terms of risk, uncertainty or complexity is, however, relevant not only in the realm of politics but also in the social systems of economy as well as in natural and social sciences [1]. At the same time and not by chance, the concept of sustainability, as difficult to determine as it may be [4], has become a common guide value, which mirrors the needs and aspiration for the preservation of the vulnerable, for balance and harmony of contradicting values and goals, the control of the present and the planning of the future.

Whereas an unbroken prediction and planning optimism in western countries could still be seen in the 1960s, with the onset of multiple crises of modernity in the 1970s, the post-war narrative of progresses collapsed [5] and the idea of control and planning has been questioned in many respects. In the meantime, the concept of resilience [6] is about to supplement the sustainability claim: instead of the notion of an active shaping of future and the focus on providing safety and order, the coping with uncertainty, the necessity of adaptation and flexibility as well as the resistance to disturbance and the avoidance of severe and potentially irreversible damages can be understood as reaction to the grown awareness of vulnerabilities, hazards and threats.

In the context of global change, forest management is also facing increasing difficulties, risks and uncertainty. The long-term nature of production in forestry can be regarded as a major problem arising from the integration of forest management into complex social and natural systems, which, by far, exceeds the scope for action, steering or influencing. In forestry, the contradiction or even dilemma between the necessity and inevitability to make long-term decisions and develop long-term management plans for forest ecosystems on one hand and the complexity of the interplay between natural and social systems, i.e. uncertainty and the lack of tangible knowledge about future on the other, is a defining characteristic and accompanies forest management and planning from the beginning.

## Management, Uncertainty and the Claim of Sustainability

The claim of sustainability usually masks the question of coping with uncertainty and risks and is therefore perhaps not by chance one of the most successful and widely used terms not only outside the realm of forest sciences and forest management, but also within: more than 300 years after Carl v. Carlowitz coined the term, foresters still claim to, on one hand, having "invented" and "further developed" the concept of sustainability and, on the other, pretending to be able to steer or manage forests in time and planning scales beyond the scope of any other trade. However, the specific discord between the reality of future uncertainty, ignorance and indeterminacy and the lack of reliable prediction on one hand and the claim connected with the concept of sustainability in modern forest management strategies on the other is quite obvious [7].

The question of how the paradox claim of sustainability, i.e. long-term planning in a situation of complexity and deep uncertainty, is addressed in forestry within strategic management has to be answered whilst simultaneously considering the almost trivial fact that the future is uncertain and all planning, i.e. future-oriented decision making, is risky—the more complex the involved social and natural systems and the longer the planning periods, the bigger the realm of non-knowledge and the more risky the planning. In contrast to the handling of uncertainty in theory or science, considering risk and uncertainties in practical decision making is something completely different: whereas one of the main goals in science is describing and carving out uncertainties or ambiguities with the help of stochastics and mathematical models (the goal of science is a proper display and description of uncertainty), the task of forest management practice is decision making: the realm of an hitherto open future is narrowed (management means the reduction or answering of uncertainty by choice). The benefits of probabilities, optimization models (under particular and limited conditions), statistical data or historical experiences are rather limited in those decision making situations, where a multitude of influencing factors have to be considered and real risk is involved—stochastics and probability calculations can hardly determine forest management decisions, since the unforeseen event can happen in the next minute.

It can also be stated that the growth of knowledge may lead in some cases to a growing realm of ignorance [8], and the ongoing and increasing insight into the complexity of natural and social systems and the interplay of their components makes us aware that prediction, thus, does not become easier.

Planning, however, not only becomes more tenuous, the more complex and long range the scope of decision is: planning becomes a risk in itself, if it is based on false assumptions or expectations and leads to decisions with potential irreversible effects and repercussions as well as costs. With regard to strategic climate change adaptation decisions, the term "maladaption" [9] has been coined.

Interestingly enough, a planning optimism is still rampant and advanced planning techniques and systems have been developed in forestry throughout the world, implicitly meeting the concerns of risk and uncertainty. Even if an explicit consideration of uncertainty and risk is often uncommon, planning systems mostly reflect the necessity to cope with uncertainty rather than to ignore or reduce uncertainty. In forestry, they also reflect the historical experiences of permanent change of the social and natural environment as preconditions of forest management [10] and the permanent change of management goals or of unexpected events as the normal condition of forestry which calls for permanent course corrections.

## Goal of the Paper

It is first and foremost the goal of this paper to raise the awareness for the challenges of complexity, risk and uncertainty for both forest management and planning whilst handling uncertainty (and related terms of risk, ignorance and indeterminacy) as given, despite all attempts to reduce uncertainty by its inclusion in the form of a mathematical or statistical formal value. At the same time, we would like to show how both planning theory and practice, forest planning instruments and established strategies must be understood as applied handling of or coping with the problems of long-term management of complex systems in the face of uncertainty, where "each action that may be chosen is identified with a distribution of potential outcomes, not with a unique outcome" [11] and steering on the basis of optimization calculus is hardly possible. Furthermore, we want to point at the fact that addressing the issue of planning and management in the face of uncertainty in theory respectively from a scientific point of view (adopting an analytical or theoretical perspective) fundamentally differs from coping with uncertainty in decision-making contexts of practical forest management. Whereas here, the problem of uncertainty is met and "answered" by particular management decision(s), i.e. complexity is reduced, forest management models and decision support tools include uncertainty (respectively a selection of uncertainties) within stochastic or probability assessments; i.e. complexity is maintained and displayed. As a consequence, the recognition of a genuine decision-making component of forest management allows recognition of the wide range of behavioural and social influences for factual dealing with uncertainty that gets lost in a narrow operation research approach.

Starting from this dilemma of strategic forest management, having to provide guidance for decision making in the face of deep uncertainty [12], this review follows the goal of pointing at different levels on which the challenge of risks and uncertainty is addressed in forest planning—in theory and practice, with regard to the organization of forest management planning as well in individual long-term decision making of practitioners.

First of all, it is necessary to at least shortly define the most relevant terms and to describe sources, types and categories as well as basic modes of handling risks and uncertainty which are relevant for both science and planning practice. In a second part, an account of the classical risk management process leads to a description of the established approaches for handling risk in forest management planning systems. The third part deals with theoretical approaches to measure risk and uncertainty and introduces forest management planning models as well as standard economic risk models. The fourth part looks at empirical studies that analysed individual as well as organizational decision making and planning processes in the face of risk and uncertainty and shows how the practical handling of the challenges of complexity and uncertainty is influenced by psychological as well as social factors. A short discussion and outlook, pointing at further research fields and questions, concludes this section.

## Definitions and Concepts

If the countless definitions regarding the term of uncertainty have one thing in common, it may be the fact that no clear dichotomy between certain and uncertain or certainty and uncertainty is given, but rather different degrees or generic types of uncertainty are described.

From the numerous taxonomies applied to the terms uncertainty, risk[1] and ignorance [13–15], we choose to follow those presented by Wynne [16•], who distinguishes risk, uncertainty, ignorance (Table 1):

Beginning with the very broad and simple understanding of uncertainty as the lack of certainty in both understanding present and foreseeing future states of a complex phenomenon (of the social as well as the natural realm and their interrelations, e.g. the consequences of long-term forest management decisions), uncertainty describes a decision-making problem in the face of an unknown future in which actions have to be taken. From this viewpoint, uncertainty is not simply the absence of knowledge: on the contrary, an increase in information respectively knowledge may—under certain circumstances—lead to an increase in uncertainty, if new knowledge on complex processes may "reveal the presence of uncertainties that were previously unknown or were underestimated" [17••]. Uncertainty, thus, has both an objective and subjective component: whilst there is no question that the future is, by definition, open and the complexity of natural and social systems leads to the lack of certainty regarding the effect of management and steering efforts, there is no objective measurement of the type or degree of uncertainty, since the definition of a decision-making outcome as risk, uncertainty or ignorance includes both individual appraisal, weighting or evaluation (in assumptions regarding probabilities and impacts of future events such as hazards) and shared values, beliefs, knowledge, attitudes and understanding about risk within a particular social domain.

Forest management—understood in the broad definitions of Davis et al. [18] and Bettinger et al. [19] as comprising all silvicultural practices and business concepts in such a way as to achieve a landowner's objectives—is addressed to the future whilst inevitably drawing from the past and present, where our data, experiences, observations and evaluations are located. Decision making in complex and changing environments under the circumstance of the often irreversible nature of forest management effects and repercussions (choice of tree species, harvesting decisions, etc.) requires more information to implement than is likely to exist: information about growth and competition, market prices, legal and political changes, and it is often not possible to define the conditional probability of outcomes or the calculation of expected utilities.

With the dynamics of global change, accelerating with vast spatial and temporal scales, uncertainty arises [20]: since experiences and know-how from the past are devalued and historical analogue is lacking, the potential for learning from past decisions in order to help inform future decisions is restricted and the anticipation of future conditions limited. Sources or causes for uncertainty can be seen on two different levels [17••]: in the ontological

[1] Please note that a prevalent distinction between uncertainty and risk in sociology connects the term "risk" (other than the objective term of "hazard" or "danger") with decision making and the corresponding expectations of decision makers regarding potential negative effects, whereas the more general term of uncertainty refers to a qualitative lack of information, the inability to develop reliable prognoses or complexity of social interaction. Uncertainty considers, therefore, also positive deviations from the expected outcome, while risk usually focuses on the adverse outcomes.

**Table 1** Basic definitions for ignorance, uncertainty and risk

| Term | Definition |
|---|---|
| Ignorance | With significant system parameters not known ("we do not know what we do not know"), there is no reliable information available regarding the scope of system behaviour. |
| Uncertainty | Important system parameters are known but not the probability distributions—with at least the scope of potential system behaviours known, "uncertainties" can explicitly be included in an analysis, but not calculated. |
| Risk | System behaviour is basically well known; chances of different outcomes can be defined and quantified by structured analysis of mechanisms and probabilities. The standard measurement of risk is the product of the probability of a negative outcome (estimated by using the frequency of past similar events) and its corresponding potential harm or damage. |

According to Wynne [16•]

dimension, uncertainty is an attribute of reality rooted in the natural variability of systems and can be described by features of complexity or, in general, the unpredictability of natural and social processes. Ontological uncertainty refers to the non-linear, chaotic and unpredictable nature of natural as well as social factors and/or processes. In the epistemological dimension, the limited human capacity to collect and process information and create knowledge or insight is understood as a source of uncertainty. Here, not only missing or incomplete theoretical knowledge about complex systems is relevant, but also uncertainty coming from available data (inexactness, inaccuracies, metrical uncertainty, measurement errors, lack of observations/ measurements/ data, immeasurable data or conflicting evidence, where data are available but allow room for competing interpretations) and uncertainty in combination with the design and application of models (e.g. setup of system boundaries, model structure or initial state; see [17••]). Additionally, in all knowledge production processes where interpretations of data are inevitable, ambiguity is involved.

In the light of the fact that uncertainty is very often only conceptualized as relating specifically to inadequate scientific knowledge about environmental systems ("scientific uncertainty"), Wynne [16•] also introduces the term of "indeterminacy" in order to highlight contingent social behaviour as an important second source of uncertainty in environmental management. This means that actors' future behaviour (social action and social values) is open and may differ from that observed in the current situation ("social uncertainty").

With regard to the socio-ecological systems that forestry deals with, it is obvious that due to the long time span between cause and effect, the high number of influencing factors and the overall complex nature of factor interplay, most of the problems that forest decision makers and forest scientist are facing, belong to the categories of ignorance or indeterminacy.

It is obvious that uncertainty is a fundamental condition for any kind of management in any other sector. The problem, however, in forest management is not only its long-term nature and the large time frame in which silvicultural decisions are embedded, where biological production and market-oriented harvesting are de-coupled. Secondly, forest management decisions may cause irreversible changes for natural capital and productivity and they cannot, by all means, easily be corrected. Decisions such as the choice of tree species or harvesting determine long-lasting production schemes and cannot be changed or withdrawn even in the medium term (as, in comparison, in agriculture or industry). Thirdly, given the complexity of forest ecosystems (with its visible and hidden interdependencies) and the coupling of forest functions, forest management bears unforeseen long-term effects and steering, rapid adaptation or correction of decisions is not easily possible, not to mention more tangible difficulties in calculating optimal rotations, the profitability of forest growing or the value of the forest.

Forestry has often been attributed (by foresters themselves) as having been sustainable for centuries now, and there are good reasons to claim a "successful forest management" of the past on a general level (mere maintenance of forest areas, permanent yield, maintenance of core forest functions). However, as forest history can tell, the concepts (and strategies) of sustainability have constantly changed and show a variability of different reference parameters, guiding principles and values, goals and strategies, which points at the fact that there is no criterion to define successful long-term steering. Secondly, despite the claims for a sustainable, long-term planning, forest history is less about stories of successful long-term planning, following a consistent set of goals that have been followed with consistent strategies and measures. It is more about permanent adaptation and effective "muddling through" in a setting of permanent change in order to mitigate risks or to cope with hazards or changes of a mostly contingent or random nature [21].

To reverse the perspective and understand that forest management is rather a product of or arises from the situation of uncertainty than it is a way of reducing uncertainty reveals an ostensible paradox: on one hand, uncertainty and a lack of knowledge are an objective fact; on the other hand, it leads to freedom of choice since the outcome is not controllable and its consequences have an effect in subsequent generations. Forest managers do not feel lost, not despite, since there is uncertainty.

## Theoretical and Formal Approaches in Coping with Risks and Uncertainty

Even if both forest scientists and decision makers in forest management will agree on the fact that the future is, by definition, open and the preoccupation long-term management does not include true knowledge about the future, but knowledge about present images or fictions of future, the theoretical handling of uncertainty and the practical handling of uncertainty via management decisions differ to a great extent.

Theoretical approaches in coping with risks and uncertainty share the attempt to make uncertainty, mainly represented by risk, visible and tangible via translating them into certain indicators or variables, completing economic calculations, providing for optimized decision making. The probabilistic calculations, models and simulations in which those uncertainty indicators are included mirror present expectations. They have to stand the test of practical application, which means that the validation happens ex post in the form of the compliance, approximation or convergence with historical processes or developments.

### Risk Management

#### *Risk Management Process*

Integrating risk and uncertainty into forest management means applying the risk management process to decisions about forest ecosystems. According to Haimes [22], this process comprises three major steps: (i) risk analysis or risk assessment (divided into risk identification and risk evaluation), (ii) risk handling and (iii) risk control. In economic theory (see previously mentioned), risky decisions have known outcomes with known probabilities, whilst, in contrast, an uncertain decision has a known number of outcomes, but the probability of each outcome is unknown. It is of particular importance for forestry to consider risk as it relates to uncertainty because predictions always include uncertainty and this renders the consequences of alternative forest management strategies difficult to assess (Fig. 1) [23••].

Forestry decisions also often concern large areas, long-time horizons and multiple stakeholders, which further complicate forest management planning and increase the uncertainty involved in it [24].

#### *Strategies of Risk Handling in Forestry*

Strategies of risk handling can be divided into cause-oriented or effect-oriented measures. Cause-oriented measures aim either at avoiding damage by abandoning risk-prone activities (risk avoidance) or at reducing the probability of damage by adopting preventive measures (risk prevention). Risk avoidance in forest management could mean stopping harvesting or thinning activities due to a temporary increase in the probability of damage [25]. Risk prevention includes all measures aiming at increasing the stability of forests such as early thinnings to influence the *h*/*d* value of the trees [26] or choosing tree species that are less prone to abiotic or biotic damage [27]. Therefore, the development of species distribution models [28] and related risk maps [29] for major tree species under different climate scenarios can be looked upon as a way to support practitioners in risk prevention. The possibilities of directly influencing damage probabilities with the help of preventive measures in forestry are limited. Examples include removing bark beetle-infested trees to reduce additional insect damage within a so-called "clean management" or treating stumps to avoid infection with fungi [23••].

Effect-oriented risk handling measures aim to reduce the amount of damage but do not reduce the probability of damage. One such measure is the transfer of risk to a third party, e.g. to an insurance company. For example, a state can assume the risk associated with large natural hazards. There is a tradition in Europe of insuring forests against fire with recent developments of insurance models, mostly in the Mediterranean countries [30]. However, the market for insurance for windstorms is still developing. An insurance model for forests in the southwest of Germany was developed by Holecy and Hanewinkel [31]. Brunette et al. [32] extended this model by scenarios that differ in terms of the link between the hazards and the parametric solutions to the actuarial problem. Brunette et al. [33] investigated the influence of public compensation for windstorm damage on possible insurance solutions and showed that public subsidies are a major hindrance to insurance solutions in forests.

#### *Diversification as a Standard Approach to Forest Risk Management*

Risk reduction implies that the potential magnitude of the damage is reduced, whilst the probability of damage remains the same. This is the case when a forest enterprise diversifies its products. The application of the portfolio theory by Knoke et al. [34•] to introducing mixed stands instead of pure stands illustrates this type of risk reduction. Griess and Knoke [35] showed an improved relation between economic output and risk for mixed stands compared to pure stands. Reducing harvesting costs after a storm event by leaving uprooted or broken trees in the forest and not replanting and waiting for

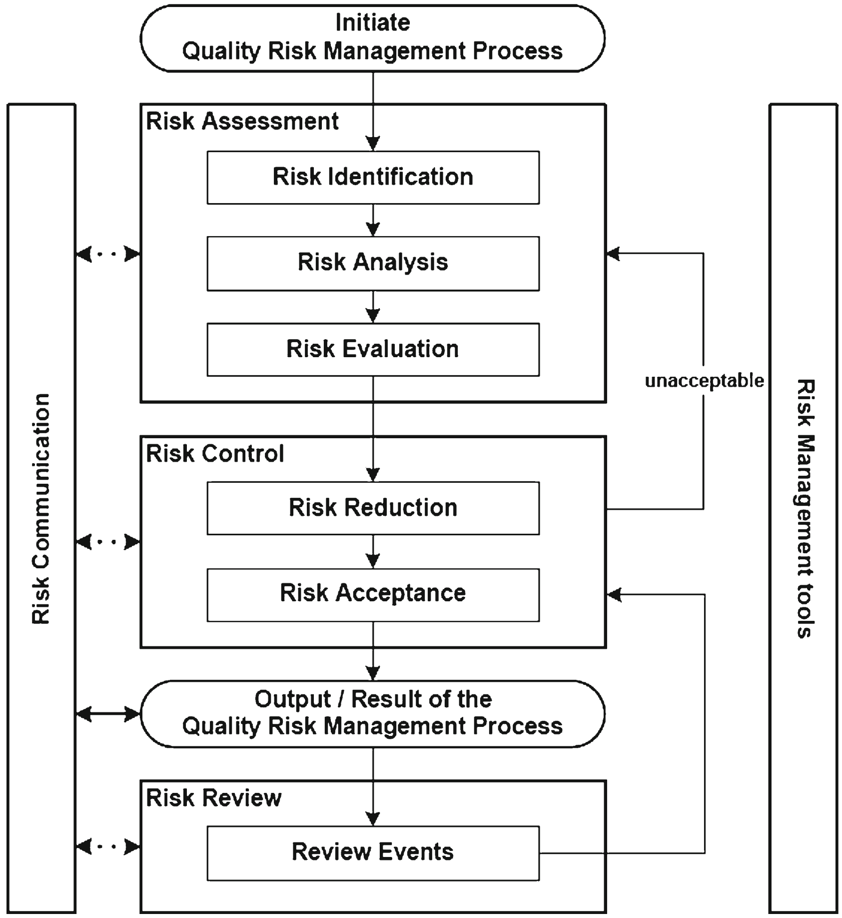


**Fig. 1** Example of a risk management process (source: GMP, Annex 20). Typical example of a risk management process, here in the form of the quality risk management process that is used to assess risks in medicinal products within a good manufacturing practice. Much emphasis is put here on the risk control that either aims at accepting or reducing the risk

natural regeneration to reduce harvesting costs may also be considered a way of reducing risk [36]. Securing the flexibility of a forest enterprise to be able to adapt to newly emerging situations may also be seen as a way of risk reduction.

## Classical Approaches to Handle Risk in Forest Management Planning in Central Europe

### *The Historical Evolution of Risk Handling in Forest Management Planning*

In Central European forestry, specifically in the German-speaking forestry community, forest management planning was for more than a century dominated by aspects that were closely related to risk handling. The classical "combined forest planning system" [37] that evolved in the history of forest management in Germany and that is still applied today consists of a combination of stand-based "single-stand silvicultural planning" and "overall planning". The latter deals with the forest enterprise level and uses sustainability indices that are based on the "normal forest" [19, 38 cf.]). The general idea of this type of forest management planning was to reduce the risk of overusing the forest resource, a problem that has—in the eighteenth century—led to the introduction of systematic forest management planning and thus to safeguard sustainable forest management. The repetition of the planning in a cycle of 10 to 20 years, although the rotation times are much longer, is itself to be seen as a way of risk handling as plans and the related risks of management are revised periodically and adapted to changing environmental conditions.

In order to include the factor of risk into forest planning, the aforementioned established sustainability indices used for controlling and, if necessary, modifying the prescribed cut aggregated from single-stand silvicultural planning have also been modified. Speidel [37] introduced a factor "*s*" in the formula of the summary final harvest planning (Eq. 1) that can be used to take into account risk.

$$m_{\mathrm{EN}} = \frac{\sum_b^{\max} M_{\mathrm{x}}}{u{-}b \pm s} + \frac{F{*}\mathrm{pZ}}{2} \tag{1}$$

$m_{\mathrm{EN}}$ = volume of the summary final harvest (in $m^3$/ha/year)

$b$ = youngest stand included in the summary final harvest

$M_{\mathrm{x}}$ = standing volume of the forest stands included in the summary final harvest

$u$ = mean rotation time of the stands included in the summary final harvest

$s$ = factor to modify the period of the final harvest

$F$ = area of the forest stands included in the summary final harvest

pZ = periodic increment of the forest stands included in the summary final harvest

The factor "$s$" can be used to modify the period ($u - b$) over which the standing volume of the forest stands (Mx) included in the summary final harvest (i.e. the planned final harvest for a whole forest unit) is distributed. If $s$ is negative, this period will be shortened, and thus, the harvesting of these stands accelerated. One reason could be the increased vulnerability of the oldest stands of a forest enterprise to a specific risk, a biotic or abiotic hazard or the risk of the depreciation of the timber, e.g. by root fungi for Norway spruce or "red heart" [39] for European beech. Speidel [37] presents one of the first formal approaches to handle risk in forest management planning on a more abstract level within overall planning for a forest unit.

For a long time and far into the twentieth century, a central goal of forest management was the establishment of a so-called "spatial order" [37], which was defined as the sum of measures to protect a forest unit against abiotic hazards (see Fig. 2). By means of a planned series of cuttings (usually in the form of clear-cuts) against the main wind direction over decades combined with measures to improve the stability of the forest edge, the spatial position of the different forest stands (see Fig. 2) should be optimized in a way that in the long term, the vulnerability of the forest to storm damage should be minimized using the hedge effect of the different forest stands. In German textbooks dedicated to forest management of the 1990s (e.g. [40]), this spatial order is still seen as a central strategic task of forest management planning in order to secure future potentials of success by this type of risk minimizing strategy. Looking at the recent history of storm damage in Europe and more specifically in Germany with a series of devastating storm events, we have to admit that this type of risk management with partly extremely schematic, artificial silvicultural measures (e.g. [41]) has failed. What remains are measures of risk prevention through choice of tree species, thinning to improve individual tree stability or the avoidance of risk-prone activities such as late thinnings in adult stands or an adaptation of the rotation times. Recently, Hanewinkel et al. [42] have shown that the vulnerability of uneven-aged forests may be rather low. Thus, a conversion from even-aged to uneven-aged stands may be a useful strategic way of handling risk.

### *Introduction of Risk into Standard Forest Management Planning Models*

The standard model that is still used as a basis for sustainability control within forest management planning is the normal forest developed in the nineteenth century by Hundeshagen and Heyer [19]. One of the central paradigms of this model is the absence of any risk; i.e. every forest stand in each age class reaches the adopted rotation time. This unrealistic assumption has been tackled by a group of researchers from the former eastern part of Germany in the 1980s. Based on the work of Suzuki [43] and Kouba in the 1970s (cf. [44]) who had introduced Markov processes in the form of survival probabilities in forest enterprise models, Kurth et al. [45] developed the "goal forest model", a modification of the normal forest model that includes risk. However, due to a lack of a sound database for the underlying survival probabilities for most of the tree species, the application of the goal forest model as a way to express risk in forest management planning remained rare. Recent investigations concerning survival probabilities of several tree species by Staupendahl and Möhring [46] and specifically by Neuner et al. [47••], who revealed that tree survival is higher in mixed stands than in pure stands, may lead to a new effort in updating the central sustainability models of forest management planning for Central Europe.

## Risk as Part of Standard Economic Models Within Forest Management

One of the first systematic approaches to include risk in a standard Faustmann approach was realized by Reed [48]. Investigating the effects of e.g. fires on the optimal rotation time, he showed that the policy effect of a fire risk is equivalent to adding a risk premium to the discount rate adopted. In a recent investigation, Loisel [49] analysed the impact of storm risk on Faustmann rotation and discussed the idea of using a risk-adjusted discount rate. A standard and very often applied method to take into account several risks within an economic calculus of forest management strategies is the application of a Monte Carlo simulation [34•, 50, 51]. More recently, Griess and Knoke [35] used this technique within a bioeconomic modelling approach of mixed stands of Norway spruce and beech. Brunette et al. [52] investigated species change subject to risk of climate change using an option value approach. One of the central aspects of including risk into economic investigations of forest management decisions is to include the attitude towards risk of the decision maker or—more generally—risk perception. In particular, the inclusion of the behaviour of a risk-averse decision maker in economic calculations is of major interest. A formal way on how to approach this from a methodological point of view is demonstrated by Knoke et al. [53] who also give a general overview on how to include risk and risk preferences in economic models.

## New Approaches: Integrated Models for Forest Management Including Risk

New approaches to integrate and handle risk in forest management are supported by the development of integrated growth and

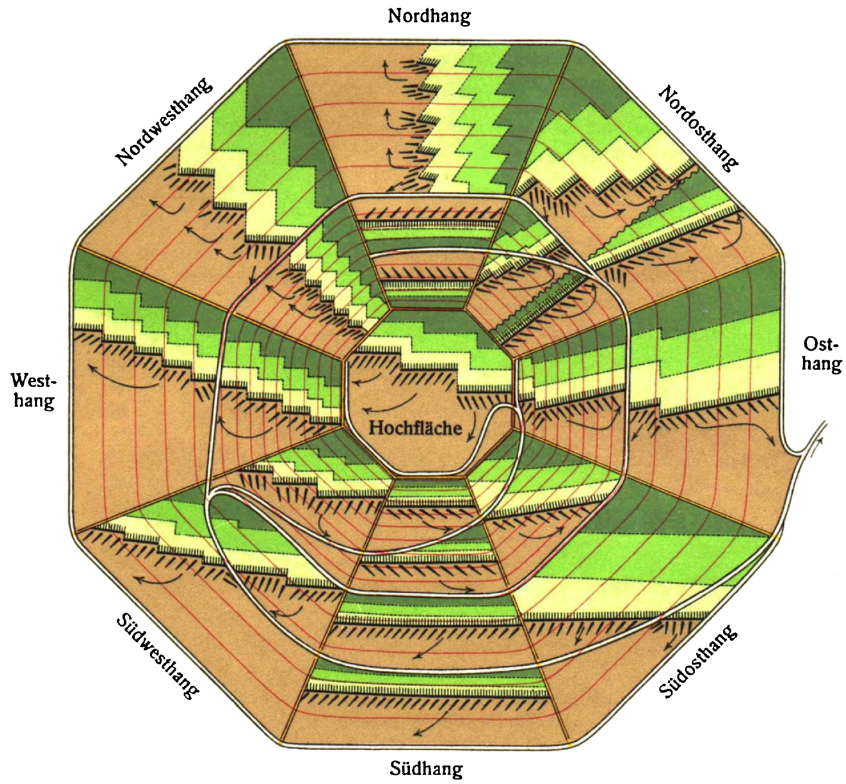


**Fig. 2** Depiction of a stylized landscape showing the result of a silvicultural system. ("Blendersaumschlag"—a specific strip cutting system, developed by Wagner in the 19th—beginning of twentieth century in southwest Germany, aiming at minimizing the risk of storm damage to forests). *Captions* describe the orientation of the slopes (e.g. "Südhang" = southbound slope), whilst the *colours* stand for the different age classes of the forest stands (i.e. the brighter the *colour*, the younger the stand), after Wagner [41] (1915)

risk models at different spatial scales. Albrecht et al. [54•] developed a prototype forest growth model that is able to consider winter storm disturbance and to simulate storm damage in forests under different forest management regimes. Zell and Hanewinkel [39] used a single-tree growth simulator coupled with an empirical storm risk model, enabling the predictions of single-tree damage to simulate adaptive management strategies under different climate scenarios. Temperli et al. [55] integrated a spatially explicit model of European spruce bark beetle dynamics that incorporates beetle phenology and forest susceptibility in a climate-sensitive landscape model (LandClim). Maroschek et al. [56] used the hybrid patch model PICUS as a core of an assessment framework to analyse and communicate the effect of management and climate change on the provision of selected ecosystem services in mountain forests. Seidl et al. [57] present a process-based model of wind disturbance impacts on forest ecosystems, integrated into the dynamic landscape simulation model iLand. An overview of how different disturbances including fire can be integrated into simulation and decision support tools can be found in Hanewinkel et al. [58]. A major challenge to further develop these types of modelling approaches is the coupling of the ecosystem model with human systems. Rammer and Seidl [59] applied an interesting approach in this respect by using an agent-based model accounting for different spatial (stand and management unit) and temporal (operational and strategic) levels of forest management decision making that was coupled with the forest landscape simulator iLand. For further take into account the risk and uncertainty in forest management decisions, novel approaches that are partly discussed in other sections of this publication such as stochastic or probabilistic approaches of decision making such as robust decision making, Bayesian updating or Dempster-Shafer theory of evidence [60••] have to be taken into consideration.

Non-probabilistic approaches have entered the field of decision making in natural resource management over the few last years, especially in the field of water management: so-called robust decision-making approaches (e.g. [61–64]) also follow satisficing approaches (see "Management Strategies in the Face of Uncertainty and Risk" section) and describe solutions that "satisfice" performance requirements over a wide range of future scenarios instead of finding a single solution that performs best in a single future scenario or for a single probability distribution. Until now, robust decision-making approaches have not been applied to forest management problems such as climate change.

## Coping with Risk and Uncertainty in Practical Forest Management and Planning—Empirical Results

### Perception of Time and Uncertainty Among Forest Practitioners

The obvious difference between a theoretical handling of risk and uncertainty in the form of modelling, simulation, scenario writing, optimization calculation, etc. on one hand and practical decision making in the face of complexity and uncertainty on the other suggests that forest management in many regards is characterized by individual, cultural and social factors shaping e.g. perception, heuristics, content and methods of evaluation and solution as well as action and planning. Although this separation of theoretical optimization calculus and the pragmatic satisficing goals of management lies at the heart of forestry, empirical studies regarding the handling of uncertainty, risk and complexity in decision-making contexts are rare. There are, however, a few exemplary studies dealing with strategies to cope with the situation of the compulsion to make decisions or act in a situation of uncertainty.

Based on surveys among stakeholders in the field of forestry in Germany and the Netherlands, Hoogstra [65•] analysed the perception of time, future and uncertainty of forest decision makers and illustrated that the future constitutes an important if not overriding consideration in contemporary decision making. Surprisingly, some studies reveal that efforts to come to grips with the future are based on notions that are less clear and long range than one might expect. Uncertainty and unpredictability are predominant factors in foresters' attempts to develop a vision of a future.

Basically, it is mainly routines established by foresters that help make the future more tangible and provide security with regard to decisions [66, 67]. Here, observations from the past and present are extrapolated to the future. Another approach to future planning involves shortening the time perspective. It has been shown that planning horizons comprising more than 10 to 15 years do not influence pending decisions [68]. As Hoogstra's survey shows, more than 95% of the foresters polled are repeatedly forced to deviate from long-term planning and had to adjust their planning occasionally or even more frequently—due to natural disasters as well as economic, organizational and societal framing conditions. In summary, these studies reveal that long-time horizons are hardly relevant for forestry decision making.

The confident assumption of forest planning that existing goal-orientated tools of forest management are reliable is also challenged by a study of Kramer [69], who empirically showed that goal-oriented steering of forestry production processes to a great extent depends on the individuality of the decision maker and his/her behaviour and the effect of operational target setting on the decision making has questioned.

With regard to the perception of risk, Blennow & Sallnäs [70] and Blennow et al. [71] showed that personal assessment of risk is decisive in the management of forest ecosystem services. Whether in the case of exposure to the climate change challenge or regarding the management of forest ecosystem services, decision makers show highly specific designs of personal knowledge maps, connected with specific heuristics, specific and individual information gathering, processing and interpretation, specific beliefs and desires and highly specific and often individual strategies of risk management.

## Management Strategies in the Face of Uncertainty and Risk

It is neither possible to address the psychology of perception, evaluation and decision making in the face of uncertainty nor the problem of different risk cultures in this paper. However, it should at least be mentioned that studies describe different general management approaches in the face of uncertainty. Basically, approaches range between optimistic, all-knowing strategies (claiming to reproduce thoroughly and correctly the dynamics of the decision field within deterministic models) and rationalizing strategies (seeking to optimize decision making by incorporating uncertainty into modelling via probabilities in order to make it tangible and measurable) on one hand, both of them following a planning approach and trying to minimize uncertainty by gaining more information. On the other hand, flexible strategies, including adaptive and muddling through strategies, follow an incremental approach, embracing uncertainty and lack of knowledge by permanent and incremental management steps not referring to long-term prognoses. Here, those choices of acting are recommended that keep a multitude of options open (see [72]). A flexible strategy is recognizable in the description of a forest as a "well-assorted warehouse", which means a broad diversification of goods and services is offered (e.g. referring largely to a diverse timber assortment) as well as in silvicultural systems where a multitude of tree species or a wide age class distribution is favoured in order to reduce production risks (see in the following).

Yousefpour et al. [60••] suggest four different types of managers to express the way uncertainty and observed impacts are taken into account by the decision maker when making decisions in forest management under climate change, reaching from reactive to forward-looking adaptive behaviour. Hoogstra and Schanz [66] differentiate between managers putting emphasis either on the past or on the present experience; i.e. they adapt in a reactive fashion to observed changes but are not forward looking in their decision-making behaviour.

The evident central role of perception, belief and values when addressing the future and taking decisions, e.g. to adapt forest management, has also been observed by Blennow et al. [73] when investigating the behaviour of private forest owners towards adaptation of forest management to climate change. Slovic [74] pointed at the fact that risk as a concept involves value judgements that go far beyond the assessment of probability and potential impacts of hazards. Blennow et al. [73] have shown that the perception of climate change as a risk essentially depends on personal experiences and beliefs of the decision makers.

Based on an extended national online survey implemented in almost all German federal states, in which district forest manager's attitudes towards the perception, evaluation and decision making concerning climate change adaptation had been measured at the local level, Detten & Faber [75••] analysed factual decision making and planning in exposure to real risks and uncertainties. As it turned out, the specific framing of the dilemma of decision making in the face of uncertainty for decision makers in forestry in contrast to the scientific challenge of climate change is striking. Whereas (forest) sciences frame climate change as a problem of missing knowledge and/or the setup of proper modelling, forest practitioners accept the situation of complexity, risk and uncertainty and interpret their situation as a legitimation problem rather than a problem of missing knowledge: since there is uncertainty, there is no "right" or "wrong" decision—only more or less legitimate decisions according to what is regarded as a "standard" within the forestry community. First of all, forest decision makers tend to make widely accepted and established decisions that are in line with those of other forest managers. Where long-term decisions become risky and where experiential knowledge is regarded as losing its value, decision makers also seem to choose strategies that provide for a handling of climate change, which guarantee a maximum of autonomy of decision making on one hand and strive for a minimization of risks via a strategy of diversification (first and foremost regarding the choice of tree species) on the other. This strategy of satisficing (a term coined by Simon [76], combining the terms "satisfying" and "sufficing" in contrast to the usual quest for an optimizing or rational management-strategy) includes the predominance of the criterion of plausibility rather than of accuracy. All things considered, the quality of both the reason and outcome seems to be subordinated to the mere capability of acting. Notwithstanding the attempts to "rationalize" forest management practices with decision support tools, forest practitioners seem to adopt a more pragmatic approach to maintain their decision-making autonomy. Established decision-supporting tools such as climate risk maps as well as references to past experiences and traditional and prevailing guiding principles help to provide adequate legitimization for decision making and management in a situation which is widely acknowledged as being risky. The study was also able to show the relevance of historical experiences as well as patterns of interpretation prominent within public communication (media), which function as scripts for the perception of current threats. As it turns out, scientific recommendations in the form of optimization models or risk calculations and practical decision making are two different things.

## New Approaches in Coping with Uncertainty: Management as Adaptation

Within the paradigm of anticipation, management is understood as an optimization task, where specified targets are followed within long-term management plans by focusing on anticipated developments and changes in natural and social systems. In comparison, management within the paradigm of incrementalism addresses the fundamental conditions of uncertainty and ignorance by focussing on the decision and management processes rather than the result, concentrating on incremental, path-oriented and context-specific decision processes; improving organizational resilience; and facilitating organizational learning rather than following long-term management strategies. The aforementioned satisficing strategies that aim for "acceptability" instead of "optimization" focus on complex decision processes and cognitive limitations as well as ambiguities and embrace theories of procedural rationality [77]. The satisficing approach can also be characterized as the paradigm of adaptation, which aims at a relative improvement rather than an optimum solution. For some decades now, the term respectively idea of "adaptation" has been regarded as some kind of solution or answer to the problem of uncertainty. It has become popular in the form of "adaptive management" or "adaptive forest management" and gained new attention in current climate change debates, implying optimism about the achievement of effective strategic management to cope with the effects of deep-rooted and long-ranging environmental changes.

Originating from the 1970s [78, 79], the adaptive management approach is intended to enable effective and flexible decision making in the face of uncertainty and has since been applied to a wide range of resource and ecosystem management problems (see [80–82]). In a "working definition", Nyberg defines adaptive management as "a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs" [83]. With its three main objectives [84]: (i) the increase of knowledge acquisition rates; (ii) the facilitation of information flow among policy actors; and (iii) the creation of shared understandings among scientists, policy makers and managers, the adaptive management approach shares an experimentation- and process-oriented view of management and focuses on learning about the cause/effect relationships between management actions and outcomes in order to adjust future plans and policies.

However, the strategy of learning from practical experiences and changing practices accordingly is based on more than a simple "learning by doing" premise. The main idea behind adaptive management is a quasi-reflexive management re-stabilization via feedback loops or feedback control, where monitoring of key indicators leads to readjustment of strategies, decisions or decision-making processes in order to establish a permanent learning process. The focus on the relative efficacy of alternative models and policies replaces the search for the best predictor and acknowledges uncertainty about what policy or practice is "best" for the particular management issue [85].

As McLain & Lee [84] and Lee [86] point out, the expectations regarding adaptive management in the sense of an adaptive social process have not been fully met. Aside from practical implementation problems (costly and controversial monitoring and evaluation processes, differences in perceptions and disagreements about values and objectives between key stakeholders), it is most notably disregarded for the various sources of uncertainty, which accounts for failures of adaptive environmental management attempts. Assumptions relating to reliable knowledge about specific issues, a given historical situation and its further development and a stable power and influence structure most likely lead to failures in the adopted adaptive environmental management processes. The question "Adapt to what?" leads to the previously mentioned problem of permanent environmental (natural and social) change, ambiguity and uncertainty. Lee [86] concludes: "Adaptive management has been more influential, so far, as an idea than as a practical means of gaining insight into the behaviour of ecosystems utilized and inhabited by humans". Without explicitly dealing with the uncertain, indeterminate and unknown, the concept of adaptive environmental management remains a purely idealistic approach.

This reticence towards adaptive management and its handling of uncertainty also applies to the method of scenario analysis that has also been promoted in forestry (e.g. [65•]). The set-up or construction of a specific number of scenarios entails the reduction of complexity (contextual environmental factors, stakeholder relationships, available knowledge, etc.) and inevitable neglect of unexpected extreme events. With the uncertain not being explicitly displayed within the scenarios and the unknown and indeterminate being out of reach, critical examination of different scenarios and discussion among stakeholders may indeed improve learning and "have a means to overcome cognitive biases" in order to possibly find "greater confidence in facing uncertainties of the future" [65•]. To suggest, however, that this also implies "more control over their future" [65] is a false conclusion, which immediately shows the risks of an application of the scenario analysis.

## Conclusions

Forest management, typically involving objectives and information concerning ecological, economic and social issues, must be understood as a way of dealing with the fact of uncertainty. The long-term perspective of forest management means that consequences of alternative forest management programmes might be hard to assess, and predictions and assessments always include uncertainty. Forest management not only concerns long time horizons, but also large areas, multiple stakeholders and possibly irreversible outcomes.

To accept the complexity and long-term nature of forest production processes and uncertainty as the fundamental condition of forest management means to question the still predominant central role of prognosis and the idea of steering forest enterprises according to constant target values on the basis of optimized plans and management solutions.

Strategies of handling risk and uncertainty in forestry are, on one hand, a theoretical issue and met by various decision support instruments as well as decision guidance in the form of scientific models and formal calculations, which include risks and uncertainties via the variability of particular model parameters and the quantification of potential loss (quantified via ascribed probabilities and possible magnitudes, derived from historical data). The idea is to inform decision making via calculating expected outcomes and describe solutions that perform best in a particular future scenario and for a single probability distribution.

On the other hand, there is empirical knowledge about real decision making by forest managers in situations which are characterized by complexity, uncertainty and risk. As we can see, real decision making in forest management under uncertainty is far from following a strict rational or optimizing strategy and instead comprises a variety of other motives such as legitimation (the decision taken has to follow predominant norms and values and first of all has to be accepted within a given social context) or the maintenance of flexibility (i.e. striving for a multitude of future options and providing for all contingencies)—which leads to an incremental, step-by-step and path-dependent decision-making approach. Despite a sound theoretical understanding of the different sources of uncertainty and numerous formal, technical as well as methodological approaches to include risk and uncertainty, the complexity and the long-term nature of forest management and permanently changing framework conditions favour approaches that maintain flexibility and offer a variety of management options instead of narrowing the space in which forest managers have to act.

Obviously, the fact that science is not immediately applied in practice is not exclusively observed in forest management. Decision making and scientific presentation and analysis are twofold. It is, however, worth noting that uncertainty as the fundamental precondition for long-term forest management has been subject to scientific research not until recent years and that the limitations of optimization calculus in complex forest management decision situations have rarely been subject to scientific debate (cf. [87]). On the contrary, forestry economics is still for the most part busy providing optimization models and stochastic decision support tools. In the meantime, the forest manager has learned the lessons from forest history and from his or her own past experiences, accepting the fact that the future will be different from expectations and calculations. Forestry means permanent change, and forest management means the inevitable coping with unexpected outcomes and events.

**Compliance with Ethical Standards**

**Conflict of Interest** Roderich von Detten and Marc Hanewinkel declare no conflicts of interest.

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