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Article

How Can Forest Management Adapt to Climate Change? Possibilities in Different Forestry Systems

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Abstract: It is only relatively recently that national adaptation strategies have begun to develop measures by which forestry can adapt to climate change; often those measures opt to use a relatively general strategy for coping under conditions of disturbance. Particularly in states using intensive forest management, such as Sweden, this approach marks a departure from current strategies for achieving maximum yield. In other countries, however, where the economic output from forestry is less significant and interests such as biodiversity, local use and tourism, may figure more prominently, the conditions for developing risk-based forest management may be more manifest. This study reviews literature on adaptations in forest management, and analyzes country reports submitted as part of an EU27 project. The study concludes that the diverse prerequisites and policies of states have seldom been reflected in the design of adaptation management actions to date.

Keywords: forest governance; forest management; climate change; adaptation; EU

1. Introduction

Even if emissions were to cease today, we would still need to adapt to the consequences of climate change that existing emission levels have caused and that impact temperature, precipitation and species suitability in different localities. Such adaptations to climate change can generally be defined as the “adjustment in natural or human systems in response to actual or expected climatic stimuli or their

effects, which moderates harm or exploits beneficial opportunities” [1]. In the last few years, a number of countries have started to develop strategies for adaptation to climate change [2,3]. These strategies, as well as the concept of adaptation itself, often entail requirements for how action among multiple stakeholders is to be coordinated. In a major land use such as forestry, which is practiced over large areas, adaptation requires actions among groups ranging from forest managers to officials at the regional and national governance levels and individual forest owners and industry [1].

However, thus far, adaptation has been less of a focus in forestry than mitigation has, and “forest-sector responses to climate change have mostly been reactive” [1]; they have shown few signs of planned adaptation and reviews of concerns such as seedling and plant suitability. Reviews of adaptation in forestry in Europe thus far have also been relatively general and descriptive. Roberts [4] has carried out a review of forestry adaptation measures and policies as described in post-2004 national communications produced for the United Nations Framework Convention on Climate Change (UNFCCC). In a study commissioned by the EC Directorate General for Agriculture and Rural Development as an initial exploration of adaptation to climate change in forestry, Lindner *et al.* [5] used a survey questionnaire to elicit existing and planned forest adaptation measures in the EU27 (for a summary, see [6]). In addition, Kolström [7] has undertaken a review based on peer-reviewed literature in the Scopus database of adaptation measures in forestry. Brang *et al.* [8] (see also [9]) have suggested that until more details are forthcoming on how adaptation should take place, forestry should follow the general aims of increasing the adaptive capacity of the forests whilst enhancing their resistance to disturbance. However, these reviews have not broached the question of how multiple actors—in very diverse states and forestry systems—are to organize adaptation or adopt what may be broadly seen as a governance perspective on forestry. Such a point of view would take into account the role of the state and industry as well as of organizational and private forest owners [10] and consider how to organize the linkages between different forestry holdings with due regard for the landscape.

The present study reviews literature on adaptation strategies in forestry and in particular analyzes country reports from an EU27 project that include reviews of the state of adaptation in each country. In light of the different management strategies described in the reports, the study addresses the following question: What adaptation actions are described for forest management and broader forest governance, and how do these reflect different forestry systems? The study suggests that although adaptation measures are defined on a relatively general level today, choice of adaptation options may differ in particular between intensive forestry states such as Sweden and Finland and states where forestry is more limited and forests are managed primarily for values other than production.

2. Theory and Methodology

Adaptation is generally conceived of as the practices or strategies that aim at adjustment in response to exposure to a stress such as climate change [11]. Undertaking adaptation measures would generally improve the resilience or robustness of forests in the face of climate change [12]. What adaptations are undertaken depends crucially on the implementing actor’s adaptive capacity, or the resources available to that actor. This can be defined on levels from the individual to the unit or state, and include support such as information and knowledge, economic resources and institutional resources [13]. Adaptation may also be classified on a scale from autonomous and reactive, to planned and proactive [11]. Planned

and proactive adaptation—as opposed to autonomous adaptation, for example adaptation as an event occurs—has at least two benefits: a number of actors and policy developments can be mobilized in preparation for potential changes and long-term planning decisions, such as the choice of forest provenance, can be undertaken to limit future risks. As a result, active adaptation actions in forestry may include both long-term planning mechanisms, such as choosing plant and other material, and shorter-term actions, such as thinning. Some authors have also suggested that adaptation in forestry may be supported by allowing natural processes to play a larger role, by either developing and steering forest management towards natural systems that may be seen as more varied and thereby adaptable (in which case actions may be seen as constituting proactive adaptation), or taking a more passive role. “Advocates of adaptation avoidance believe that human interference could have unintended consequences in natural systems, given the great uncertainty in ecological understanding of climate-forest interactions” [14]. However, Colombo recommends that even in such a case, “forest managers should encourage policies that facilitate adaptation by natural processes. For instance, they could allow natural disturbance to increase or rely more on the intense selection pressure from natural regeneration by seed, instead of planting trees from local seed” [14].

Adaptation also includes actions at different scales; this approach is highlighted by the inclusion of a governance perspective, that is, broadly, a focus on both public and private actors on several levels spanning at least the range from national to local [3]. Given the importance of small-scale forest owners in many states, perspectives on how adaptive capacity, for instance information resources for individual forest owners, can be strengthened through better communication or policy development are highly relevant. Adaptive measures for forestry may be decided on, and implemented, at the forest management level (owner or manager of a holding) or a higher governance level; for example, the government can undertake to disseminate information enabling forest managers to achieve lowest common denominator of knowledge on adaptation. What makes a perspective beyond that of the individual holding important in forestry in particular are the broader biodiversity considerations where forests are concerned. Including a landscape perspective and attention to the spatial arrangement of species is important to provide a basis for minimizing fire and insect damage and to assess connectivity between different parts of the landscape and ecosystems [15]. It has also been suggested that application of adaptation strategies and options together can yield progress towards adaptive management, which encompasses a large variety of different measures that support and promote the stress resistance and resilience of forest ecosystems [1].

This study summarizes the descriptions of adaptation actions in country reports produced within the EU Cost-Action Echoes project on impacts, mitigation and adaptation strategies for forestry in European countries (23 country reports submitted by experts in the areas for autumn 2008; reports from Lithuania, Latvia, Norway and Portugal were not available at the time). Given that the work examining adaptation actions in forestry in European countries prior to 2008 was relatively limited, the reports constitute a salient overview. However, the data in them are limited by the different methodologies and selections made in each national case. For instance, some authors provide rather detailed data in strict forest management categories; few describe exact legislative requirements; and some exercise their expert judgment to put forward potential management options of their own. The data are also limited by the authors’ knowledge of strategies and actions. A further constraint is the fact that adaptation

policy is a very quickly moving field of policy, one in which developments may have taken place in many instances since submission of the country reports in 2008.

Despite these limitations, the data may be used to illustrate the relatively extensive similarities in the types of measures suggested in comparatively different countries. The study may thus provide a starting point for discussing the basis on which to develop the relevant actions in different forestry systems.

3. The Development of Policy on Adaptation in Forestry

3.1. Forestry in National Strategies for Adaptation: Background

The country reports illustrate the very large breadth and variation in the development of adaptation strategies in forestry, as well as the variation in how countries approach the drawing up of adaptation strategies in general. At the time of this study, most countries base their approaches on sustainable management principles and many (although not all) also have general adaptation strategies. A specific adaptation policy for forests is described as lacking in Italy, Serbia, Croatia, Germany (on the federal level [16]), Greece, and the Netherlands. Ireland also lacks an official policy, but has a pertinent statement published by the forest service. These countries also exhibit very varying development with respect to adaptation in general (for a survey of selected countries, see [3]): one finds a range from those with a well-developed adaptation policy in general, such as the Netherlands and Germany, to those entirely lacking such a policy, such as Italy and Greece. In Greece, however, although official strategies do not exist, the WWF and International Union for Conservation of Nature (IUCN) have made a prominent contribution to developing recommendations for adaptation measures that include forestry, and the country report for Greece draws attention to these suggested measures.

In countries with clearly articulated policies on adaptation in forestry, the formulation of those policies has been a relatively diverse process that in different cases has included the regional level, part of national strategies, or the development of forest-specific strategies. For instance, in Wallonia in Belgium, an expert group under a regional ministry has developed recommendations for forest owners and managers that the ministry has since committed itself to. In some countries, such as Bulgaria, Hungary, Spain, Slovakia, U.K. (including Scotland, Wales, England and Northern Ireland) [17], Sweden and Finland, policies for forestry are part of the work of larger national commissions or facets of action plans on climate change or adaptation in general. In these countries, adaptation in forestry may be addressed as part of a more general national strategy and later or simultaneously in forest-specific strategies (as, for instance, in Cyprus). In other countries, such as the Czech Republic and Slovenia, adaptation policies in forestry have instead been developed within a national forestry program which may subsequently be included in a national climate policy program, as is the case at least in the Czech Republic. In Switzerland, given the large autonomy of the cantons, the development of guidelines has taken place on a canton-by-canton basis, with some acting as leaders and others report having strategies under development. However, the Swiss country report notes that although a cross-sectoral adaptation strategy is being developed, its impact may be limited by the autonomy of the cantons.

Considerable variety can be seen in the adaptation measures described in the reports. Noting that few concrete measures have been undertaken so far, the German report states that forest adaptation measures show considerable variety in terms of their status (existing, planned or proposed) and scale of implementation (stand, regional or national level). Similar variety also exists within countries that have to some extent formulated adaptation policies at different levels or as part of broader adaptation policy development. Given the recent nature of these efforts, many measures may as yet be unfinanced or responsibility for them has been delegated among different actors. For example, the Swedish report notes the role of the many individual small-scale forest owners in developing adaptation, for which information measures are the sole support strategy suggested by the state thus far. It is also noted, for instance in the Czech Republic, that the National Forestry Program launched in 2008 does not distinguish between public and private forests, although specific adaptation measures may differ based on ownership. In many cases, recommendations have yet to be translated into specific management measures for different site characteristics, that is, measures specifying how a forest holding is to be utilized and how biodiversity or species distribution is to be taken into account (Belgian country report).

Variety, as well as a lack of specification and detail, may thus occur both at the level of proposed measures in diverse policies (given the recency of adaptation policy development) and as a result of the variety of methodologies used in the country reports. Some reports note that given how recent the development of adaptation has been, they have included measures suggested in the scientific community or developed in bodies other than those that shape policy on the national level.

3.2. Adaptation Measures

Adaptation in forestry can be divided into several different types. The types of adaptation and adaptation strategies that have been suggested in the country reports are summarized in Table 1. The measures are similar to those found by Kolström ([7], identical to [5] with the exception that the research does not include pest disease and fire management). Kolström breaks forestry adaptation actions down into forest regeneration (including selection of species provenances and genotypes), nurseries and forest tree breeding, tending and thinning, harvesting, pest and disease management, fire management, infrastructure and transport, forest management planning, and further adaptation options in risk management and policy. Innes *et al.* [18] similarly describe forest management strategies as including landscape-level strategies; the use of reserves or protection; strategies for maintaining forest health, for instance to minimize fire and pathogen risks; management options related to productivity such as rotation length changes and species changes; monitoring; and genetics. (See also [19-21] for categories of adaptation options developed in North America).

To highlight the broader governance aspect of forest management and the measures to be implemented by actors outside of the forest management sector, the presentation below is structured in terms of the implementing actor, encompassing governance on a broad level as well as more specific forest management. This differentiation is undertaken in order to distinguish higher-level actions (e.g., improved monitoring and research, policy advice and improved disturbance management) from actions that may be possible at the level of forest management, such as changes in forest structure and management in response to stresses such as fire and drought. The third grouping covers larger-scale measures (e.g., for forest managers whose work encompasses the larger, ecosystem level), nature

protection options, and genetic variety development/choice. Finally, the last category covers options that do not involve active management or that target infrastructural measures (e.g., proposals for forest roads, which were less prominent in the material). The analysis also illustrates potential differentiations within countries that correspond to the respective remits of different actors: for instance, proposals regarding public forests attributed in the report to the French Forest Service ONF are distinguished from those submitted on private forests by the example of the large private forest manager SFCDC France. In the results, listings of countries suggesting specific measures are not exhaustive, but serve only to exemplify country reports highlighting the issue at hand; a more detailed differentiation beyond the sub-categories of measures described below is precluded by limitations of the material. Finally, as the Belgian country report notes, the implementation of these different measures will require that the recommendations be translated into specific management measures depending on species distribution and how the forest at the location is to be utilized, in other words, combinations of forestry and biodiversity management [22].

Table 1. Types of management actions, by implementing actor.

| <i>Measures at higher governance level</i> | <i>Measures at forest management level</i> | <i>Large-scale measures (beyond general forest management)</i> | <i>Additional options</i> |
|--|--|--|---|
| <ul style="list-style-type: none"> • Improved monitoring and research • Policy advice and information • Improved disturbance management | <ul style="list-style-type: none"> • Changes in forest structure to increase diversity <ul style="list-style-type: none"> ○ Change tree species/diversity (increase resistance) ○ Regeneration/ natural regeneration ○ Rotation length ○ General (improved) management/ silviculture ○ Increase forestation ○ Continuous cover/ selective cutting • Forest management in response to additional stresses <ul style="list-style-type: none"> ○ Fire ○ Drought ○ General water management | <ul style="list-style-type: none"> • Forest management on ecosystem level • Protection forest • Longer term (genetic variety) | <ul style="list-style-type: none"> • Passive adaptation • Other |

3.2.1. Adaptation Measures at Governance Level

The measures which the different countries highlighted for higher decision-making levels have rather a lot in common. Measures under “improve monitoring and research” indicate a largely similar lack of knowledge across the countries, signaling in particular a need for monitoring with attention to different capacities that could be expected to change with the advance of climate change. The need to

improve disturbance management indicates that in many cases crisis plans have yet to be formulated and that the more urgent needs are disturbances such as insects and pests. Changes in game populations may also be required. The development of policy advice and information is largely defined as needed to bring information about potential risks to different interests.

3.2.1.1. Improve monitoring and research

A number of countries mention general measures to develop research and a knowledge base on climate change as it may impact forest management. The actions proposed include the development and/or application of forest growth models under different scenarios, the introduction or use of adaptive species, and research on the risks of pest outbreaks (e.g., Spain, France, Austria, Belgium, and Hungary). Suggestions also cite the development and/or extension of monitoring systems, for example to encompass a broader range of parameters than at present and to accommodate continuous change or problems caused by extreme events today (e.g., the French Forest Service ONF, Belgium, Cyprus, Slovenia, Sweden, Slovenia). It is also proposed that information systems on climate change and adaptation (Austria) and integration of resources on the issue of adaptation (Germany) should be improved.

3.2.1.2. Policy advice and information

Given the extensive changes that the reports identify and require, for instance improved monitoring and research as well as better disturbance management, a large range of countries also emphasize a need to modify policy advice and information. Suggestions with similar aims for reviewing national recommendations advocate, among other things, modifying existing regulation (e.g., stimulation of adaptation-favorable forestry practices) (Slovenia), developing additional national recommendations and guidelines for forest management (Finland, Bulgaria, U.K., Germany, Hungary, Spain, the French Forest Service ONF), and improving advice to employees of the forest service, foresters, private forest owners and society (Wales, Hungary, Slovenia), and generally improving decision support and open-access information systems (Germany, Slovenia). Many of the ideas put forward target the need for policy advice and information in particular areas, for instance in relation to disturbance management (treated in more detail below). Such measures with regard to policy advice and information include, for instance, development of forest fire prevention plans at different administrative levels as well as campaigns for and the education of forest managers in fire prevention and mitigation (e.g., Hungary); in a similar vein, Sweden points out that it may be able to learn from examples in southern Europe when developing its policy on controlling forest fires. One suggestion is also made to improve the international dimension of policy development by strengthening international cooperation on adaptation in both agriculture and forestry in the EU (Slovenia).

3.2.1.3. Improve disturbance management

The need to improve management of disturbance in particular is similarly highlighted across a number of countries, and sometimes seen as marking a new perspective on how forests are managed, an example being the suggestion that forestry needs to develop a “crisis management culture” (put

forward in relation to the French Forest Service ONF). A high proportion of the suggestions target the development of crisis or contingency plans and early warning systems (including indicators), and in some cases the identification of zones at risk for storms (Austria, Belgium, Spain, U.K.). Specifically targeted sectors include fire, pest and disease control and in some cases erosion control as well (Bulgaria, Cyprus, Sweden, Wales, U.K., Hungary). [23] It is proposed, for example, that these be reflected in the development of new, localized protocols for site description that are adapted to changing environmental conditions (the French Forest Service ONF). References are also made to the need to review forest sectors other than forestry; one aim here might be to reduce damage by game and wildlife species by, for example, adjusting game management practices (Austria, Cyprus, Sweden, Wales, French Forest Service ONF on public forests; Belgium also suggests that game pressure should be limited).

While the means by which such actions are to be undertaken are described to a lesser extent, which may reflect the relatively limited development of clear adaptation steering mechanisms nationally [3], suggestions for policy implementation include developing subsidies for protection against pests, diseases and forest fires as well as for the restoration of damaged areas (Hungary), providing logistic support for forest owners in the case of large-scale disturbances (Germany), and directing public aid to support adaptive measures (Czech Republic).

3.2.2. Adaptation Measures at Forest Management Level

This category includes the more specific actions which can probably be decided on at forest management level and which are probably those envisaged by much of the policy and advice formulated in the above categories (aside from management measures that the state itself can implement).

Many of the adaptation measures that may be taken at forest management level advocate increasing diversity as an aim in itself, or with the aim of increasing the proportion of species that are deemed drought-tolerant or otherwise adapted to potential climate changes, or that are well suited for a particular area rather than part of larger monocultures. Diversification is considered important for improving risk planning and management, including all actions from widening the range of genetic material and developing more mixed forests with a larger variety of tree species to varying management systems with mixed ages (different-age composition) in forest stands and varying timing of operations (Scotland, IUCN and WWF Greece, Wales, Belgium, Austria, Bulgaria, Czech Republic, French Forest Service ONF on public forests, Finland).

More specifically (see below), suggestions were put forward advocating higher diversity rather than monocultures; the inclusion of local species and broadleaves; continuous cover forestry, especially in vulnerable areas; and natural regeneration. In contrast, more active management measures are also proposed, including replacement of stands at risk and early and intensive thinning. Where rotation lengths are mentioned, suggestions mainly call for a decrease in length, potentially as a response to increased production. Recommendations are also found that forest management should include management to decrease the risk of, among other problems, fire and drought/water stress.

3.2.2.1. Regeneration to increase tree species diversity and creating mixed stands

The suggestion that tree species diversity be increased may be based on several different lines of reasoning. One approach would include species that are more resilient to the impacts of climate change, for instance drought, or other site conditions (Belgium, Austria, Bulgaria, Czech Republic, Germany, U.K., IUCN and WWF Greece, Austria, Czech Republic, Irish statement, Bulgaria, SFCDC France on private forests), and to include other species among identified sensitive monocultures, replacing parts of these with more resilient species as has been done using Norway spruce forests in Germany or France. The species included may be either species that are natural to the area, or exotic species that are better adapted to the anticipated conditions under climate change. A difference in the types of species selected can be seen where the French report, Slovenia and Hungary discuss the choice of species to reflect natural stands, for instance, with the aim of changing or restoring non-native stand types to natural forest. The U.K. country report suggests that locally native species that are well adapted to the planting site should be chosen, augmented by non-local material where this is needed but with a choice of species of “continental European origin” (U.K.). Leaving more leeway for choice, the Slovakian and Bulgarian reports discuss that tree species composition can be chosen to ensure optimal regeneration or to give priority to resistant species (Slovakia, Bulgaria), while the Swedish Commission on Climate and Vulnerability and for instance SFCDC France opt for including fast-growing tree species in some stands, for instance to decrease risks from storms and fires.

Another, potentially complementary line of reasoning is that species diversity in itself provides for a more resilient environment. The Greek country report, for instance, notes that mixed forest stands are considered to be more natural and resilient than monocultures to changing climate conditions and the consequences of climate change, such as pests (IUCN and WWF Greece). The Swedish Commission on Climate and Vulnerability notes that mixed stands can be used to counter the risk of drought by increasing variation and distributing risk. In some cases, the specific suggestion is made that plantation woodlands need to be diversified (Wales). One report also explicitly points out that efforts to foster such silviculture may require diversification to be supplemented by industry actions to improve value chains for broad-leaved forest (Austria).

Certain reports also discuss the means for regeneration. Priority or increased application of natural regeneration is discussed by Belgium, Bulgaria, the Czech Republic, Germany, the IUCN and WWF Greece, Hungary and the U.K. The French Forest Service ONF, responsible for public forests, notes that natural regeneration can be used where possible, depending on the site, anticipated changes in climate and access to seed trees. In response to these kinds of priorities, the Czech Republic report notes that it may be necessary to extend the legal time limits for the establishment of stands to allow for natural forest regeneration (Czech Republic). Hungary suggests that the number of seedlings in plantation forests should be decreased (Hungary). Other countries suggest that the timing of planting may need to be reviewed (e.g., early planting to take advantage of spring humidity, proposed, for instance in Cyprus).

3.2.2.2. Improved management/silviculture

Most countries also discuss the direct changes in management/silviculture that need to be undertaken in response to climate change. In general, these changes include maintenance of forest edges, enhancement of resilience through young, in some cases drastically thinned, stands (mixed stands as regularly suggested above), taking into account increased growth, and limiting fire and storm risks in stocks (cf. the French Forest Service ONF). Concerns on maintaining forest edges to avoid edges that are very exposed to wind and to keep the forest canopy closed are mentioned by, among others, France, Sweden and Hungary.

The recommendations put forward generally call for the increased thinning of forest stands, but with some variations. Relatively strong and early thinning is suggested by Sweden, Finland, France, Germany, and Bulgaria, the latter three also mentioning the aim of increasing health status, decreasing water competition and enhancing stand stability (or in one case productivity). In contrast, the Hungarian report suggests a diversified practice involving more intensive thinning in plantation forests and less frequent thinning in natural forest types, which would provide optimal conditions for natural processes (Hungary). In addition, Hungary and Belgium highlight the need for planning the management regime based on local site conditions, possible effects of climate change, and the target species; the Hungarian report also suggests potentially consulting forest managers and authorities. The Spanish report advocates generally increased attention to the selection of the thinning intensity and thinning interval.

Another proposal put forward is to decrease rotation length in order to reduce the risk of exposure to hazards such as storms or fire (thus also decreasing costs and increasing potential revenue from production). This rationale is put forward by the Czech Republic and the U.K. for species particularly endangered by climate change. The Irish statement on forestry suggests that decreased rotation length may be relevant more generally to take higher growth rates into account, while the Germany country report suggests limiting rotation length as a way to decrease mean standing stock. For Finland and Sweden, shorter rotation cycles are expected for management planning, while in Greece longer rotation periods may be needed to compensate for reductions in growth rate due to water constraints (IUCN and WWF Greece). One suggestion highlights the need for relating any adaptations to the market by reviewing target diameters as well as risks (health, quality degradation) in relation to market demands (French Forest Service ONF).

3.2.2.3. Continuous cover/selective cutting

Continuous cover/selective cutting mechanisms are also advocated in the material, even among countries where these have not been the norm. For instance, the U.K. report suggests that alternatives to clear-felling systems should be considered where suitable sites and species combinations allow (U.K.), whereas the Swedish report notes that continuity forestry can be practiced in some areas. The Hungarian report notes that although selective cutting has been rarely used in recent forestry practice, it should be applied increasingly instead of clear cutting. However, the same report also points out that both the ecological and economic consequences of such management options have to be further clarified. Cyprus suggests the use of continuous-cover forestry in mountain areas, and Germany and

Hungary propose that small-scale cutting can be used to increase spatial heterogeneity and more diverse stand structure. The French Forest Service ONF suggests that stands could be uneven-aged but that the aim where the growing stock (basal area) is concerned should be to achieve the same target diameter as in even-aged stands. In some, but not all cases, such recommendations are put forward together with management practices that aim at “close-to-nature forestry” (IUCN and WWF Greece, Germany), such as natural regeneration and mixed stands (Hungary).

Afforestation is also suggested in some cases as a means for achieving continuous cover; for instance, the Bulgarian report notes that the country has extensive swampland acreage where forest shelter belts could be developed to protect arable land. Afforestation of agricultural fields with fast-growing tree species is suggested by the Czech Republic; the possibilities for this have been investigated in Sweden as well.

3.2.2.4. Forest management in response to additional stresses (drought and water management, fire)

A major concern with regard to specified stresses likely to increase with climate change is that of water stress and drought, which in turn increase susceptibility to fire. Noting that future planting policy needs to take potential water shortages into account even in areas where these do not occur today, water stress, especially in summer, will influence which trees are considered for planting or are otherwise regarded as resilient and thus worth maintaining in a stand structure (Irish statement, Cyprus). Other means of retaining water, such as maintaining shrubs or the tending of forest springs, can also be important (Cyprus, Hungary). Soil water storage and soil protection are necessary to both retain water and maintain soil fertility (Austria, French Forest Service ONF, SFCDC France).

In general, assessments for forest management also need to include responses to a variety of potentially adverse situations (Spain). These risks may include a higher frequency of storms or cyclones as well as the effects of higher wind speed on stand stability (Irish statement, Sweden); responses may take the form of measures to prevent forest fires and the development of “fire-smart” management (Slovenia, IUCN and WWF Greece). Although it acknowledged the risk of increased forest fires, Sweden noted that adjustment to this contingency has thus far been limited.

3.2.3. Adaptation Measures on the Ecosystem Level

This section indicates that measures cannot only be made on the stand level, but need to be made on the ecosystem level as well; presumably these are actions that need to be undertaken primarily on the national level but which large forest owners may also find necessary. Measures on the ecosystem level are put forward with regard to, among other things, the need to avoid fragmentation of habitats and the need to improve the ecological connectivity of the landscape by linking habitats (U.K. in general, IUCN and WWF Greece, Scotland). In addition, state measures such as developing irrigation plans for state-owned land (for instance Forest Parks) are suggested (Cyprus).

Some of the countries also suggest increased protection of forests, for instance through measures creating or assuring networks of old stands and improving consideration of the environment (for instance French Forest Service ONF, Finland).

Although genetic stocks are not areas highlighted in this study, mention should be made of measures to conserve genetic reserves and increase genetic variety, for these are among the options suggested to

provide a genetic stock with the capability to adapt to changing conditions (Slovakian report). To support this, the report notes that conservation measures for habitats (rather than for a single genotype or rare species) are needed, and that fragmentation and low forest densities, which impede pollen and seed movement, should be avoided (the IUCN and WWF Greece).

3.2.4. Other Adaptation Measures

Finally, the reports put forward a number of measures that do not fit within the broad general categories above. These include explicit recommendations advocating passive adaptation. Passive adaptation here implies that forest stands are left to natural succession and the natural development of stand dynamics rather than being actively managed (IUCN and WWF Greece). This suggestion thus marks a departure from proposals advocating the development of a more “natural” forest through active management, sometimes including explicit attention to resilience-heightening features such as diversity.

This category also includes a number of suggestions focusing on other opportunities and costs that adaptation may result in. These include the need to view adaptation in forestry not only in relation to forest management, but also in relation to forestry as a sector. For instance, accessibility and forest roads will be impacted by climate change, causing higher costs for road maintenance (Sweden, Hungary) and a need to consider climate change in culvert and road design (U.K.). Forestry machines that retain soil quality will need to be developed or chosen (Hungary, Belgium). In addition, one report also noted that adaptations within forestry will need to be geared to market factors, profitability, specific local impacts of climate change and current adaptiveness, as well as the expectations of owners and customers (SFCDC France). The French report thus highlights that not only natural or climate change considerations will play an important role in ultimately influencing the types of adaptation options that are chosen in any given case.

4. Discussion and Conclusions

In general, the results illustrate the need to develop national-level monitoring of factors likely to figure more prominently with the advance of climate change, and to develop crisis plans that include risks from disturbances such as pests and fire. The proposed management-level measures advocate higher diversity in preference to monocultures; inclusion of local species and broadleaves; and, to some extent, the use of continuous-cover forestry, especially in vulnerable areas. These suggestions diverge notably from intensive forestry with even-aged monocultures. Suggestions are also made for natural regeneration in some areas. This may potentially be a cost-effective way of adapting forests to natural conditions, but it may also decrease production rates in comparison with intensive forestry. Contrasting with such proposals are the more active management measures suggested by many countries, including replacement of stands at risk, and early and intensive thinning. Most suggestions advocate decreasing rotation lengths, potentially as a result of increased production. Some country reports also suggest that forest management should include measures to decrease the risk of, among other things, fire and drought/water stress.

Adaptation thus places increased requirements on long-term planning along more dimensions than production parameters (now also risk parameters). Differentiating factors such as a focus on more active management with a choice of specific tree species, thinning and other management mechanisms

for a site, can also to some degree be contrasted with more close-to-nature systems, which emphasize natural regeneration or, at the extreme, “passive” adaptation.

In general, the adaptation measures proposed could be interpreted as advocating that forests should be managed more for resilience to stresses than for maximal production or intensity of forest use—a position that may be at odds with industry requirements in more intensively managed systems. The differences in national forest management systems across Europe are significant. Countries such as Sweden and Finland, which have extensive forest covers and where forestry plays an important role for the GNP, practice relatively intensive forestry, including clear-cutting, planting rather than natural regeneration, even-age stands, and fertilization [24]. On the other hand, in these countries, the forests have often been described as semi-natural, given that they cover large areas [25]. Other countries, such as Slovenia, practice close-to-nature forestry to a large extent, using mainly natural regeneration and retaining natural age structures in stands. The Slovenian report notes that the country uses a variation of silvicultural systems which include logging for group and single-stem selection and create a patchy forest structure with mixed, uneven-aged stands. However, forest areas in continental Europe are more often smaller and fragmented [25]. While they may be managed more for “naturalistic” characteristics (*ibid.*), they may nevertheless be highly altered through fragmentation. On a global level, it has been noted that “European forests are among the most intensively managed forests in the world” [26].

Ideals of “naturalness” and the prerequisites for developing this characteristic in different types of forests may thus vary significantly from country to country. The governance systems of the different countries also vary significantly, from more centralized countries to federal and decentralized countries with extensive regional self-determination [3]. For instance, the Swiss report notes that although a cross-sectoral adaptation strategy is being developed, its impact may be limited by the autonomy of the cantons. Other studies note that federal systems in particular may be complex and invoke cross-scale linkages between many sectors as well as variations in the level in which authority in forest matters may be vested [27]. The potential to steer adaptation in forest management thus differs between countries.

Implementation may also differ greatly between actors within the national context. In each country, forestry as a sector of the economy has varying importance for employment in the different countries as well as regionally, which may result in different choices on the local to national levels as to what measures can be taken. Large-scale forest owners (companies) with significant land ownership may be able to develop adaptation management policies of their own that are implemented depending on forest type in different areas and that fundamentally affect large areas; on the other hand, economic considerations may limit such development or implementation. For small-scale forest owners lack of information and awareness about adaptation options may be a constraint in addition to economic concerns.

Taken together, these concerns mean that different countries, areas and actors will have different possibilities to steer adaptation in forestry. This is likely to shape their respective adaptation strategies and the possibilities for these to be implemented. The choice of adaptation options will thus likely be relatively complex even in cases where information and policy have been developed and communication measures for forest management formulated. Making such choices may require considerable knowledge, competence and commitment, for implementation at the local level. Different

groups may require varying forms of subsidies or support for developing their respective adaptation actions, and the suitability of the management actions will vary from area to area (depending on natural prerequisites or use).

Although this survey has not focused on the means by which measures are to be implemented, given the relatively recent development of suggestions for adaptation measures in forestry, issues of subsidies, implementation and control of implementation, prompt questions in many of the cases described. In some cases industry or forest owners may have started to institutionalize adaptations even if state policy has only developed to a limited level, for instance in response to storms or other events. In other cases, policy may have preceded practice, as in the suggestions for planned adaptation largely described above.

The extent to which adaptation measures are being implemented, and the tools by which this can be achieved, are thus important issues for research. Additional questions include the extent to which efficient means of reaching private forest owners exist. This research has not examined whether the present development of adaptation strategies corresponds with the perceived vulnerability (or to what extent limitations on strategies exist in terms of priority, time and the resources allocated to adaptation in forestry). Associated questions include whether sufficient research exists on risk-distributing mechanisms and strategies, given that in some locations forestry has thus far aimed more to optimize yields.

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